Main Injector Digital Dampers

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What's a digital damper?
What can the damper do?
Operational Performance
What's coming soon?

What is a digital damper?

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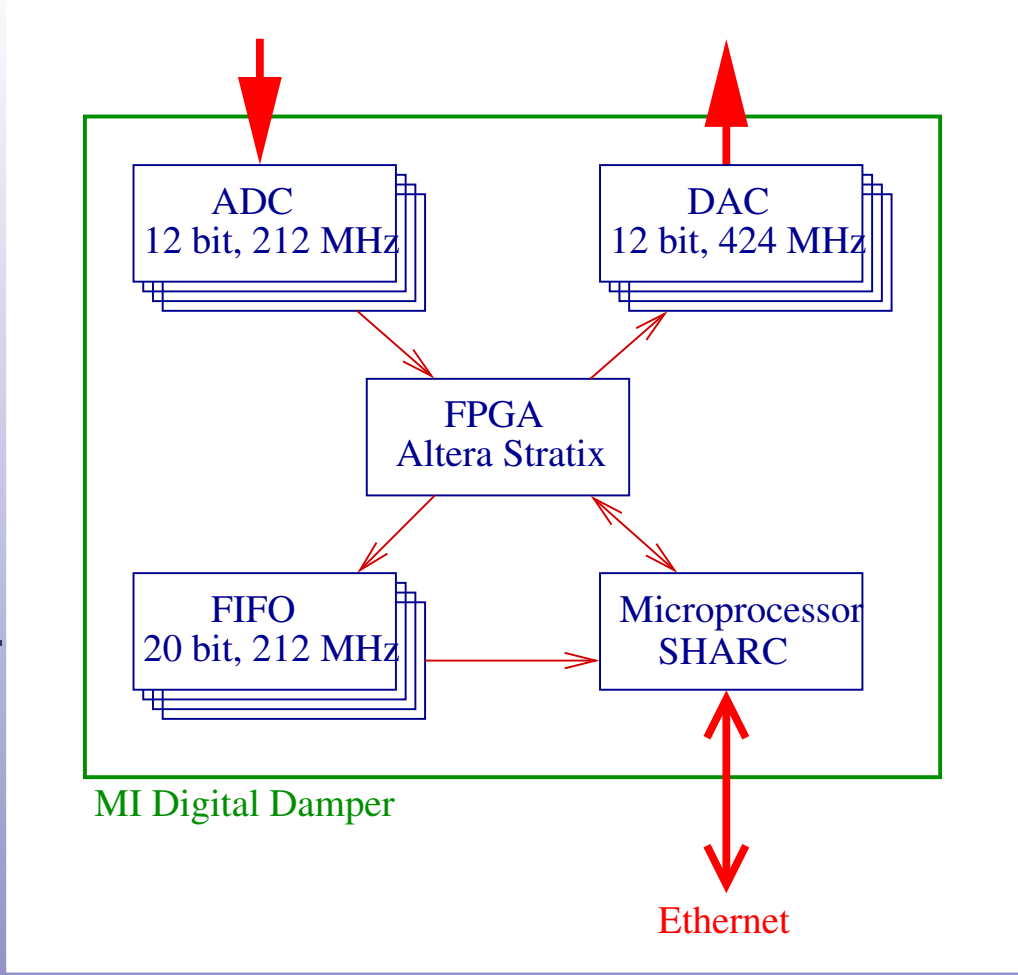
- Concept: everything is digital
  - ⇒ Spares are easy—just install software on a new board
  - ⇒ Digital is reproducible
  - ⇒ General purpose hardware easy(ish) to adapt to another machine or another function



What is a digital damper?

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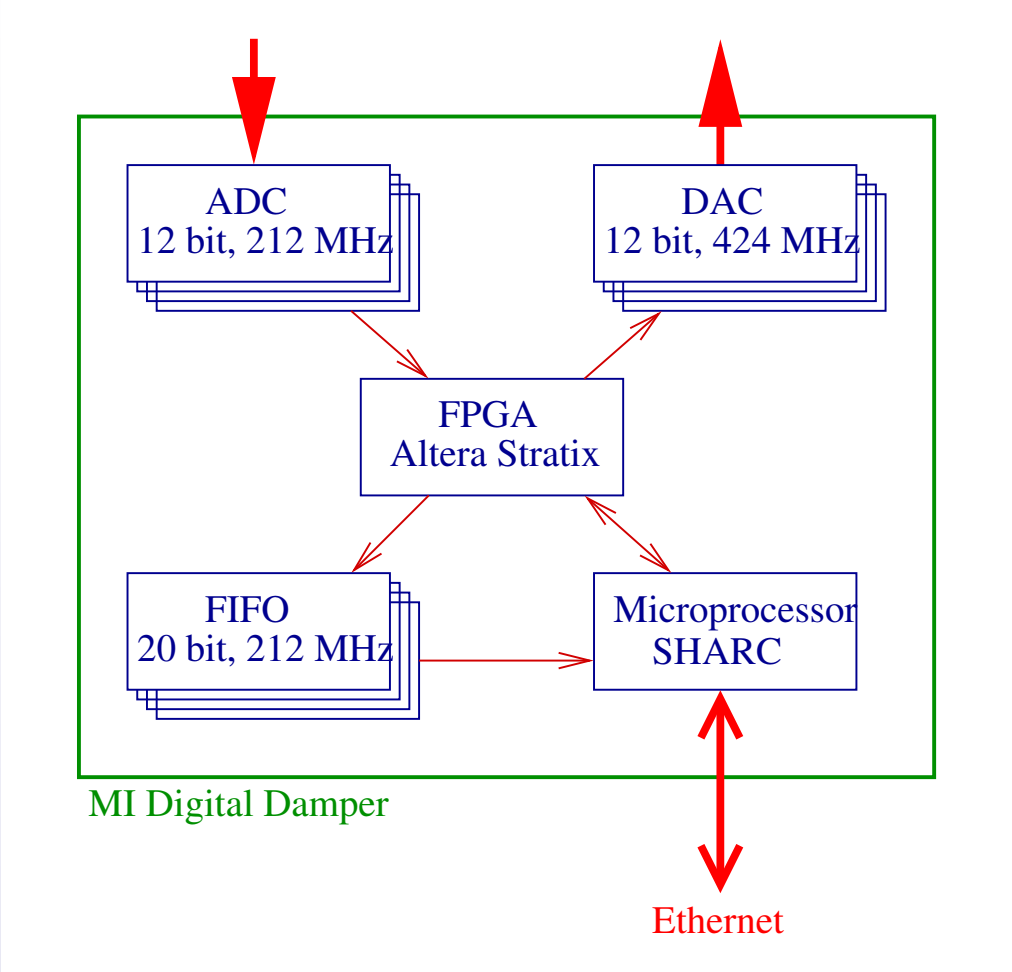
- Features:
  - ⇒ ADC: 4× RF frequency, DAC: 8×
  - ⇒ 4 channels of input and output (X,Y,Z,spare)
  - ⇒ 4 fast FIFOs for detailed data acqisition
  - ⇒ Simple protocol over TCP/IP for control
  - ⇒ Even has a web server!
  - ⇒ Independent settings based on MI RF state
  - ⇒ All ACNET-controlled



Damper Spotting

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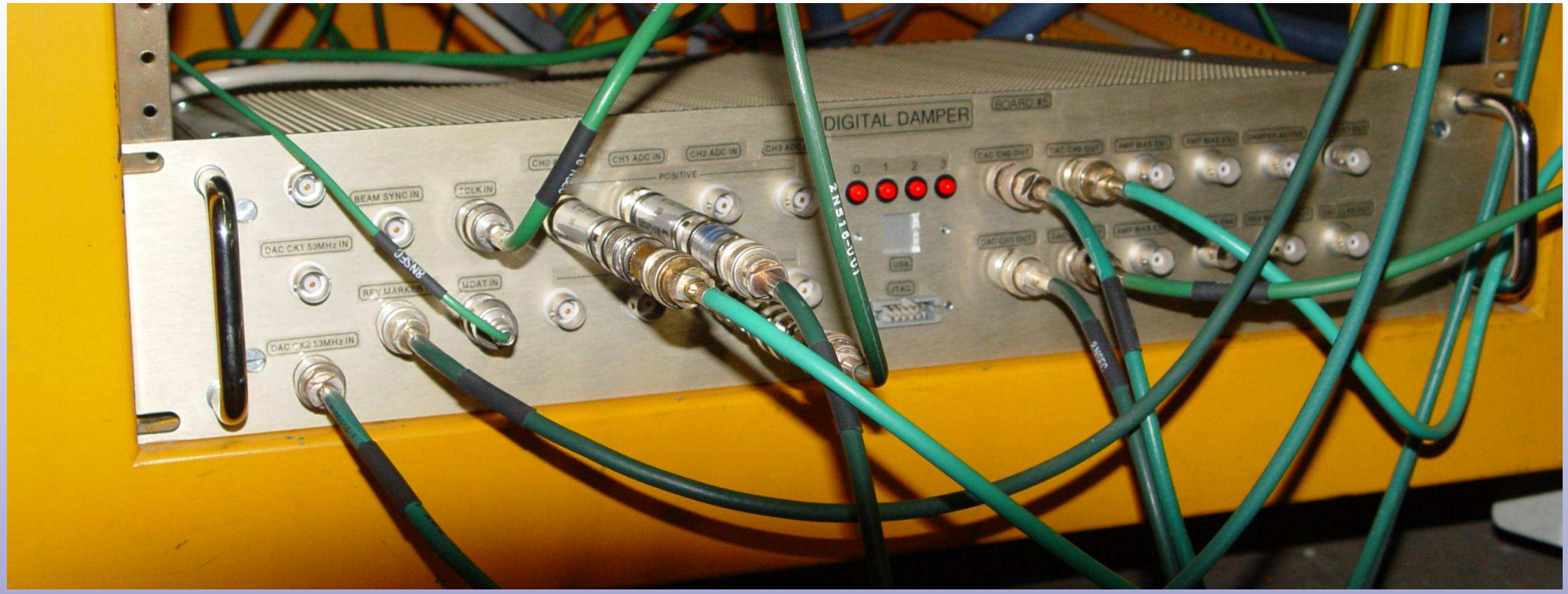

- 5 damper boards built
- 1 has dead DACs
- 1 used by pbar (Ashmanskas)
- 2 at MI 60 (one semi-production, one for testing)
- 1 in hospital

Pickups & Kickers

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- Transverse: Stripline pickups and kickers inherited from Main Ring
- Longitudinal: RWM for pickup, 3 broadband cavities for kick
  - ⇒ Built by Dave Wildman
  - ⇒ Similar to Recycler, but better HF response

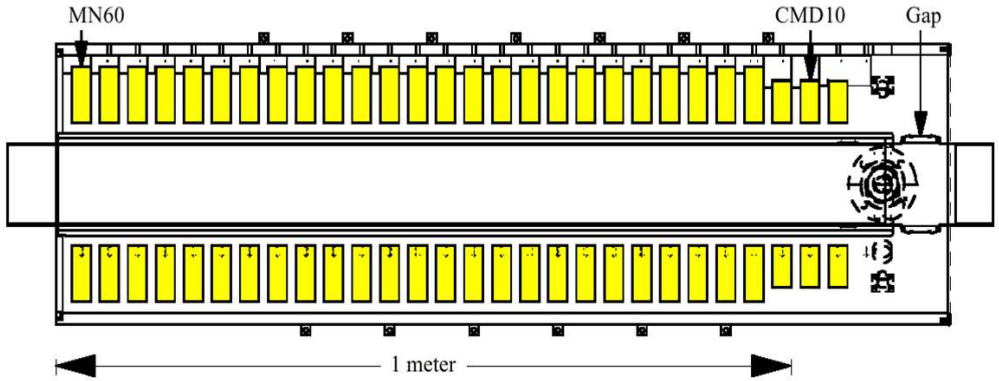

Figure 1: Schematic drawing of Recycler Wideband RF Cavity

- Switches/cables for p/pbar timing, all other hardware by Dave Wildman
- Everything just works

How does it work?

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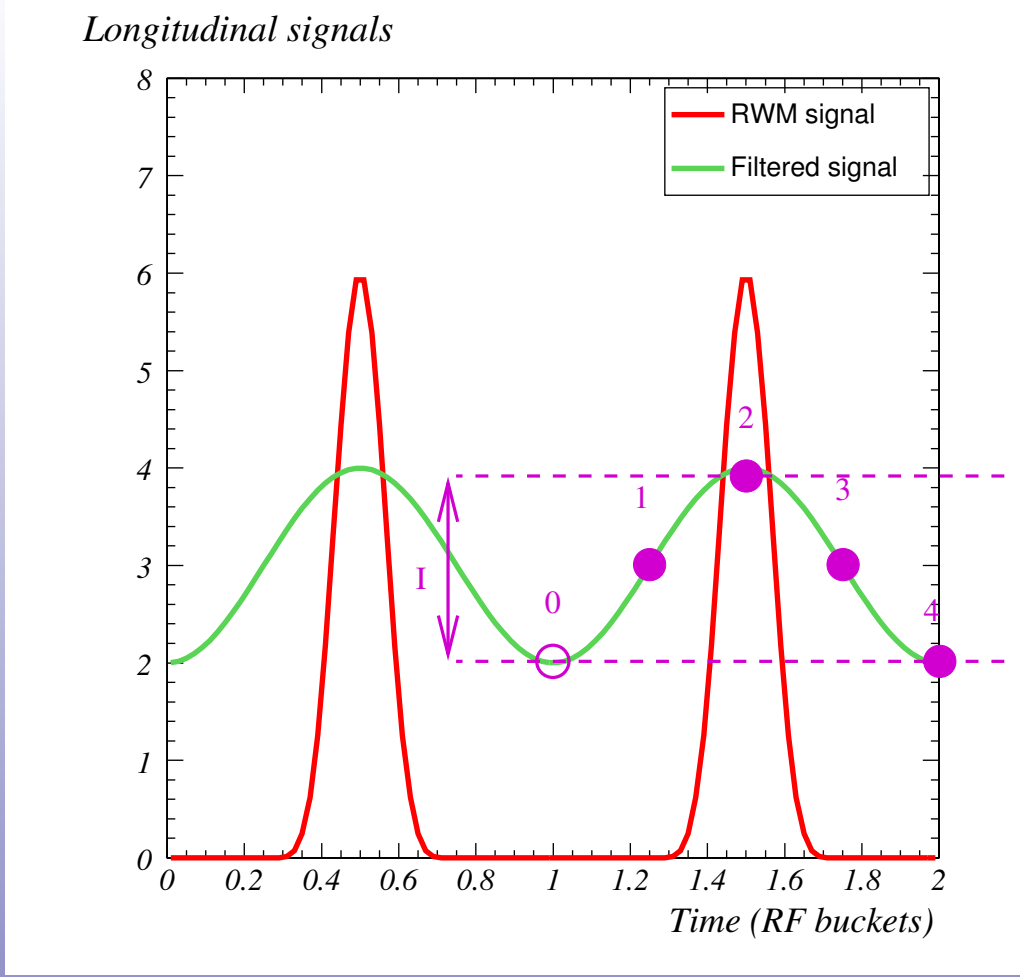
- All bunches are treated as independent
- FIR filter calculates change in transverse position or longitudinal phase.
- Kick in the other direction!
- Signal passed through 70MHz low-pass filter so we don't miss fast spiky peaks
- Sample 4 times per RF bucket
- Can adjust ADC sample timing by 1/4 bucket digitally—fine tuning with cables



$(3-1)$ gives longitudinal phase.

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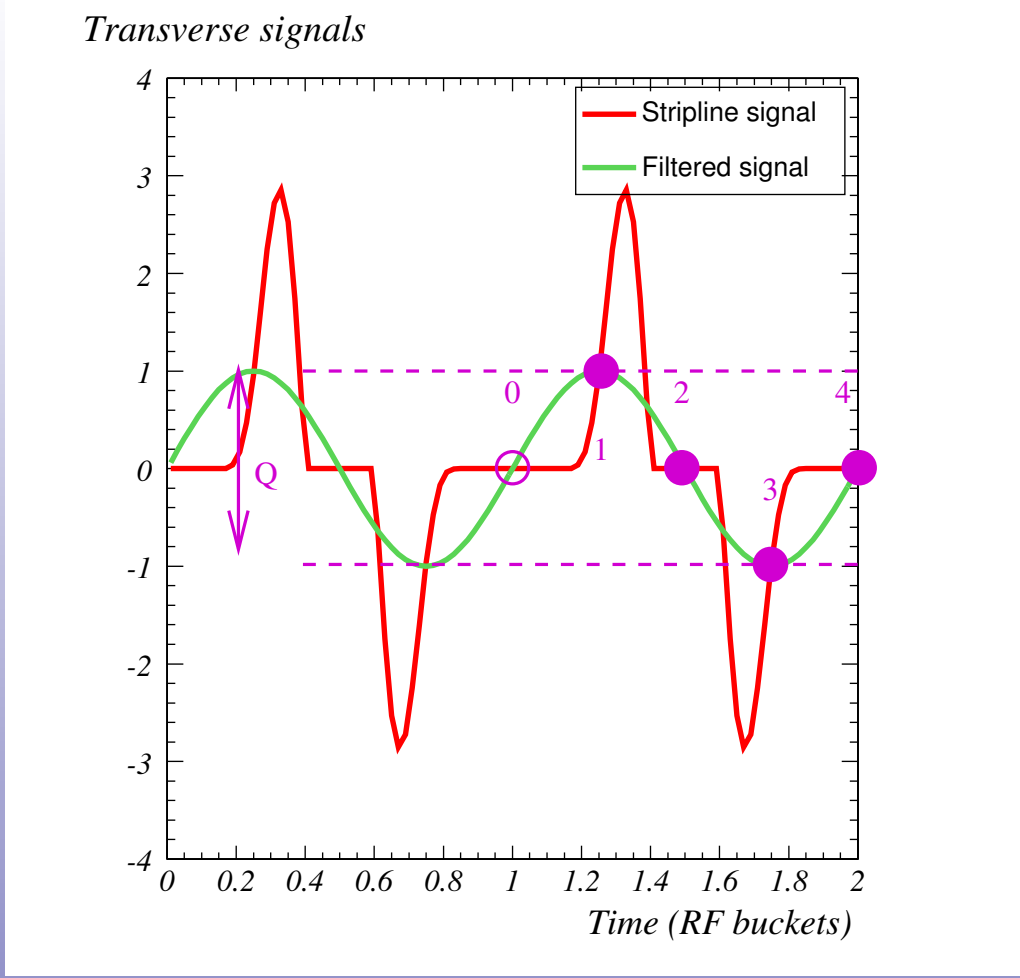

$(3-1)$ gives transverse position.

Clock Issues

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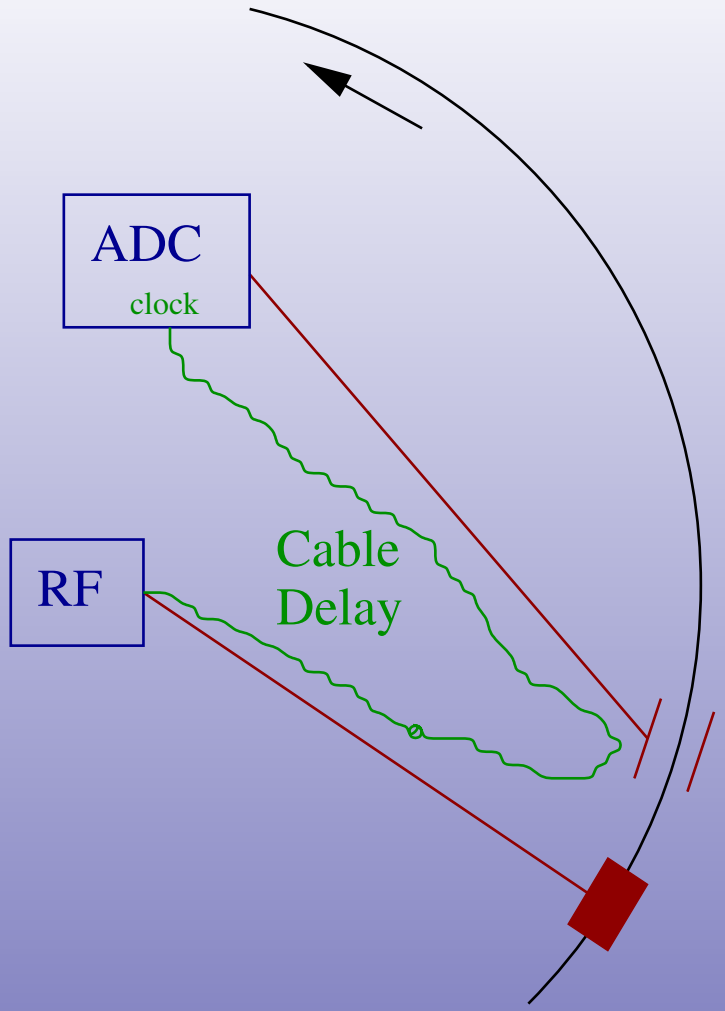
- MI RF: 52.8 MHz → 53.1 MHz
- FPGA clocked with MI RF, so stays in synch with the beam
- 588 clock ticks is always one MI turn
- Cable delay RF clock to match beam signal (so ADC samples stay in same place during frequency sweep)



Signal path in damper

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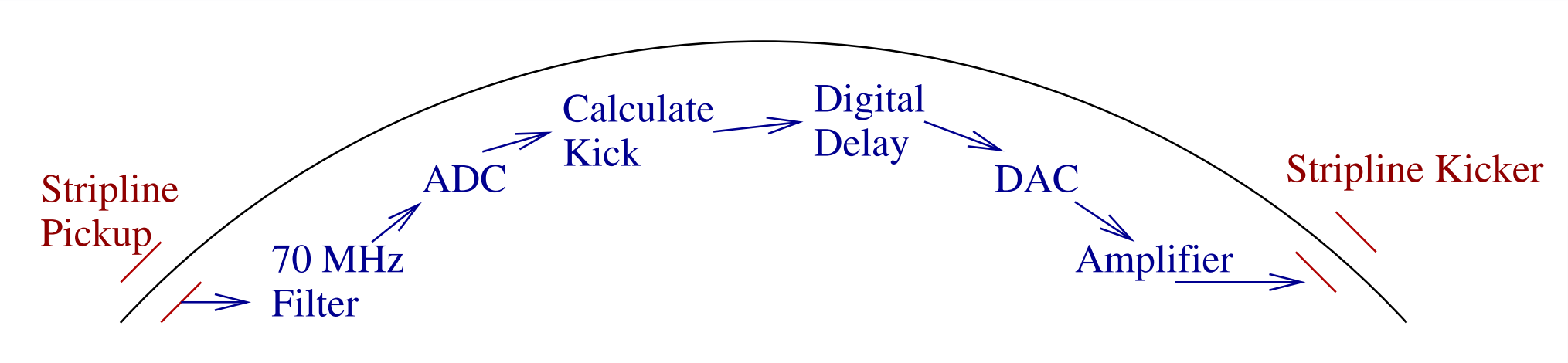

- Transverse dampers: 3-turn FIR filter to get transverse motion
- Digital delay $\pm$ 1/8 bucket
- Kick the beam on the following turn
- Longitudinal dampers: 8-turn FIR filter below transition
- 32-turn above transition
- 128-turn for 2.5 MHz
- All ACNET controlled

What can the damper do?

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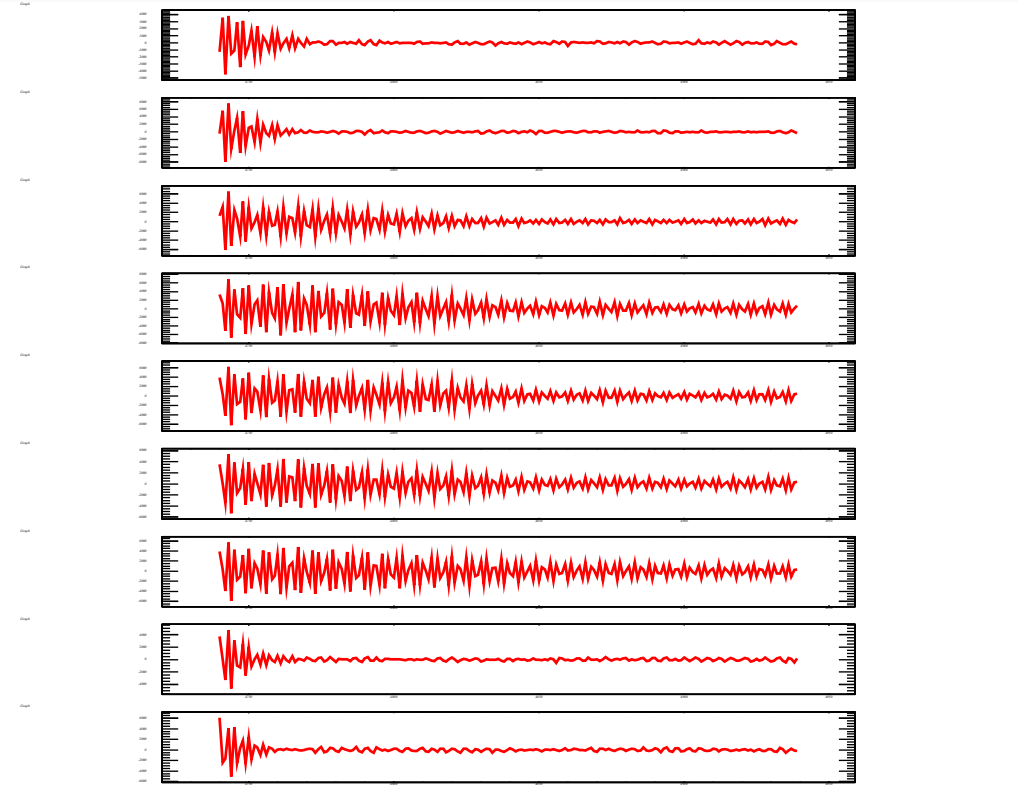
- Damping injection oscillations
  - ⇒ In X



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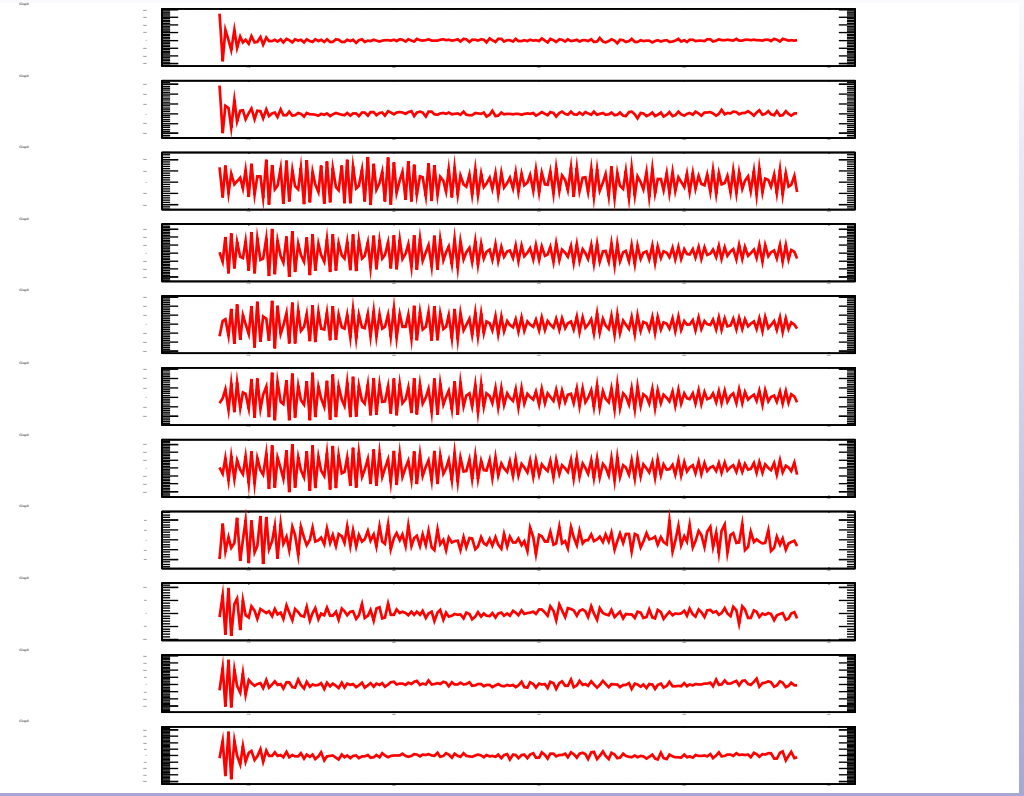

What can the damper do?

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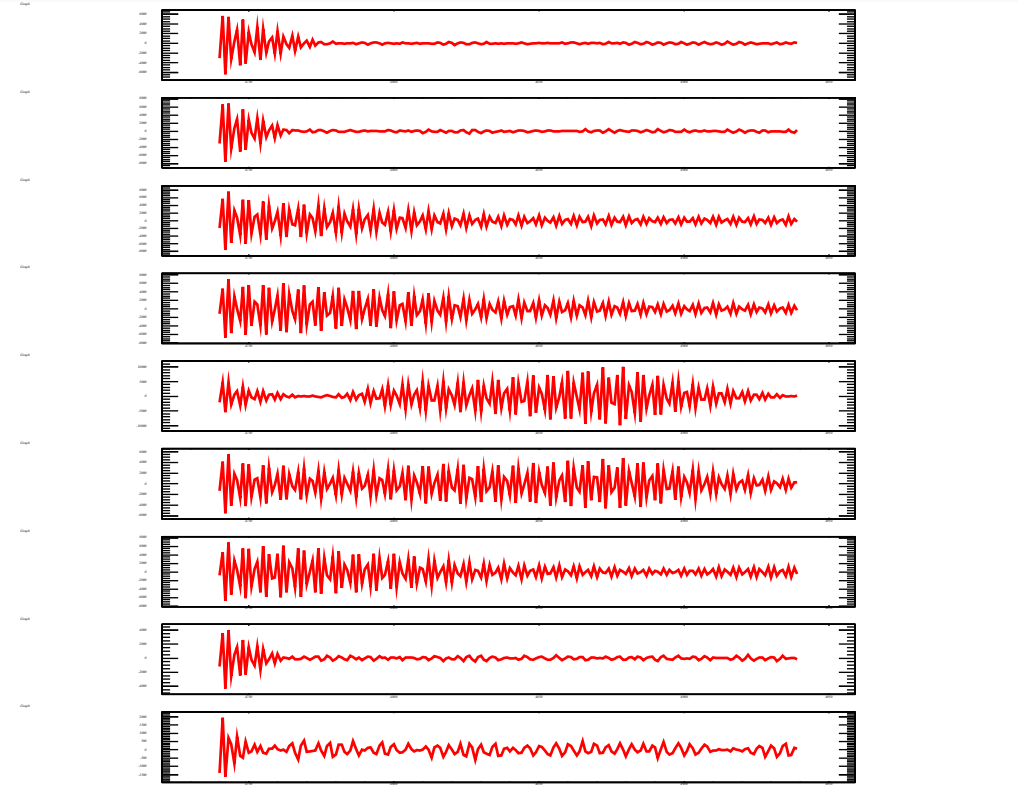
- Damping injection oscillations
  - ⇒ In X
  - ⇒ In Y
- Pinger can ping individual bunches



What can the damper do?

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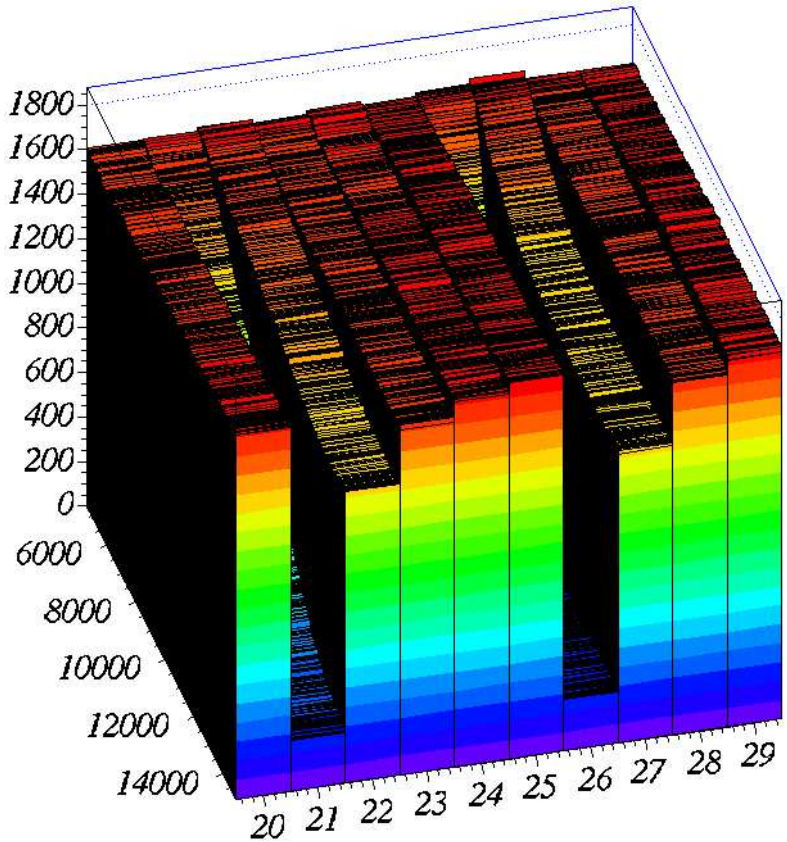
- Damping injection oscillations
  - ⇒ In X
  - ⇒ In Y
- Pinger can ping individual bunches
- Can antidamp and kill individual bunches



Beam diagnostics

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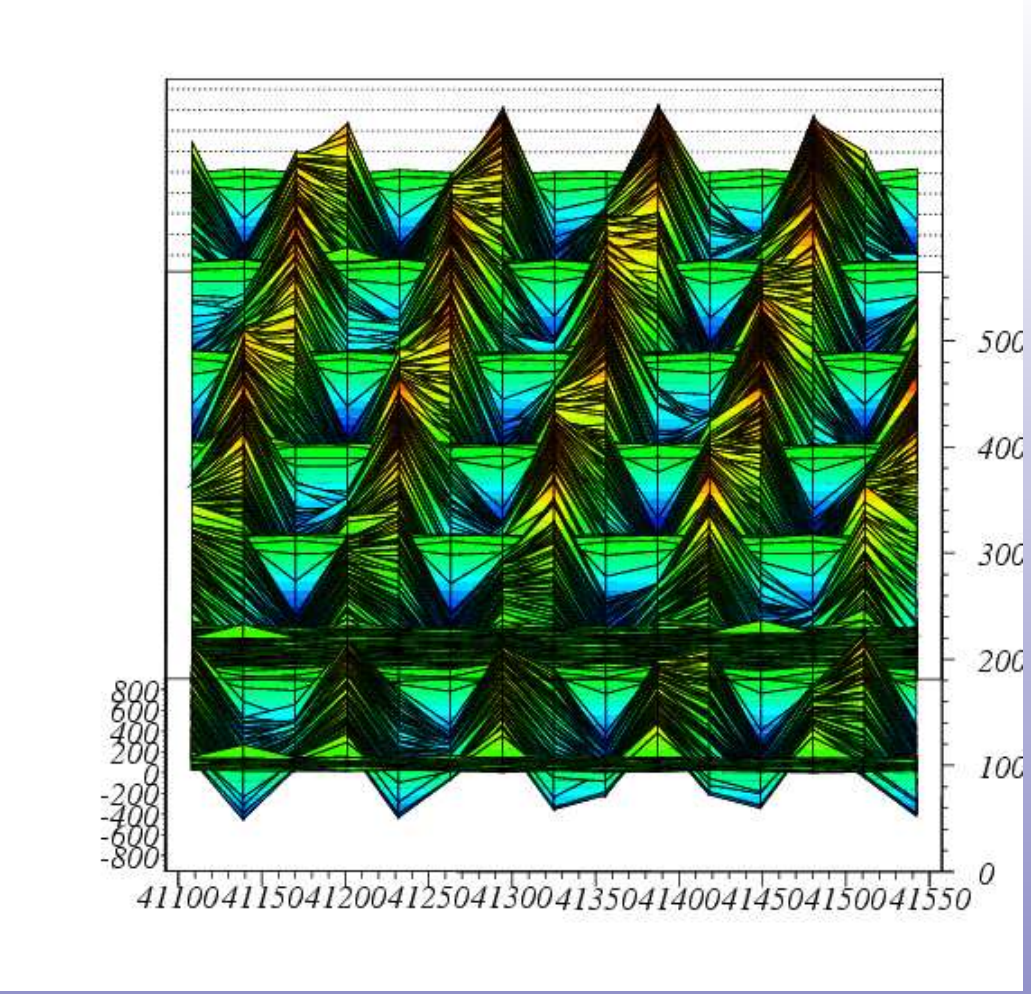
- Damper can take data for some or all bunches in the machine for many turns
- (bunches * turns = 65536)
- Every Nth turn
- Plot shows a number $\propto$ longitudinal phase vs bunch and turn number
- Mode 1 oscillation after injection of 6th batch in NuMI multibatch cycle, at high intensity



How does damping help me?

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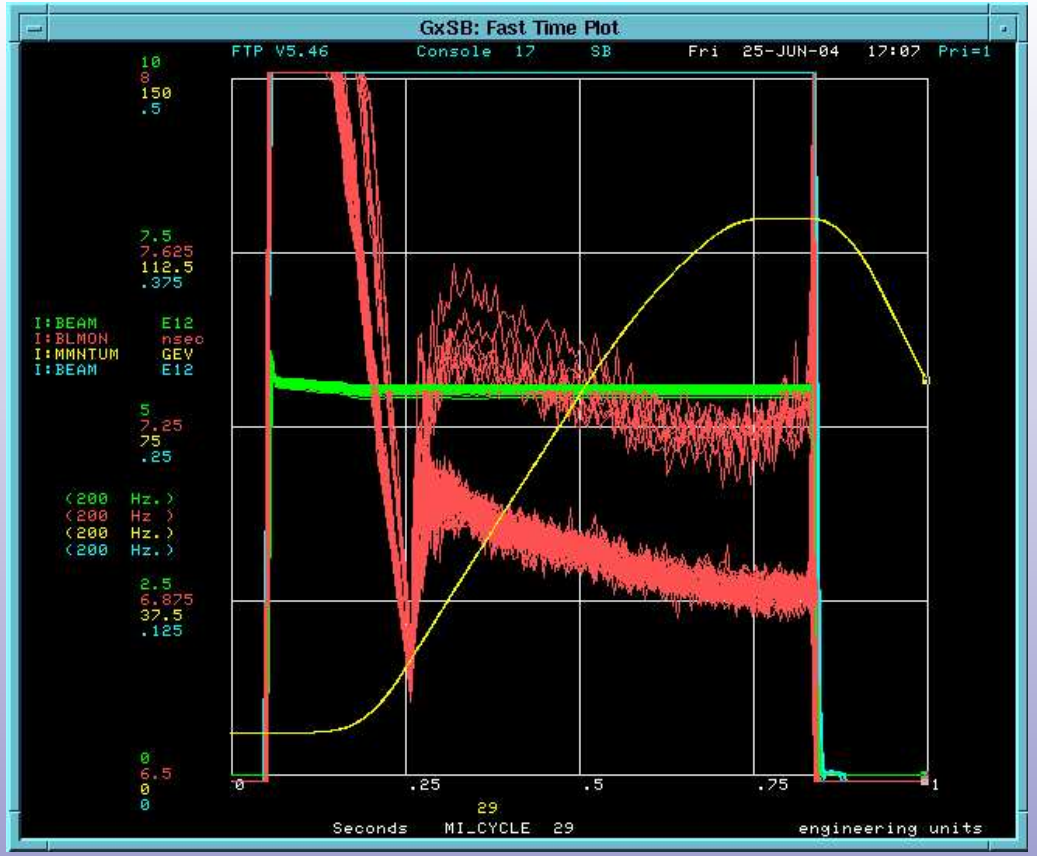
- Dampers have been/ will be used for:
  - ⇒ Stacking cycles
  - ⇒ Proton Coalescing
  - ⇒ NuMI multibatch cycles
  - ⇒ 2.5 MHz: pbar shots, fast transfers to Recycler
  - ⇒ Eventually damp both 2.5MHz and 53 MHz periods during Tev shots



- Red trace: I:BLMON.
- Upper traces without longitudinal dampers
- Lower traces with

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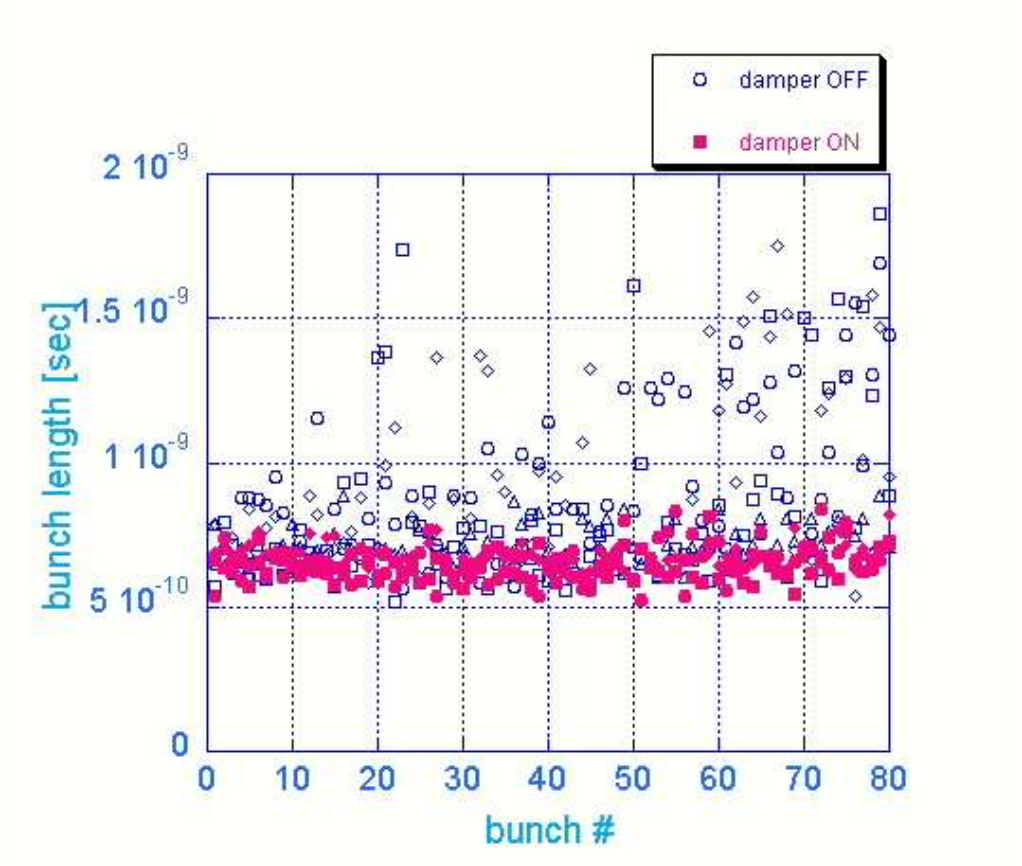

- Bunch length to pbar with and without dampers

Damping on $2B

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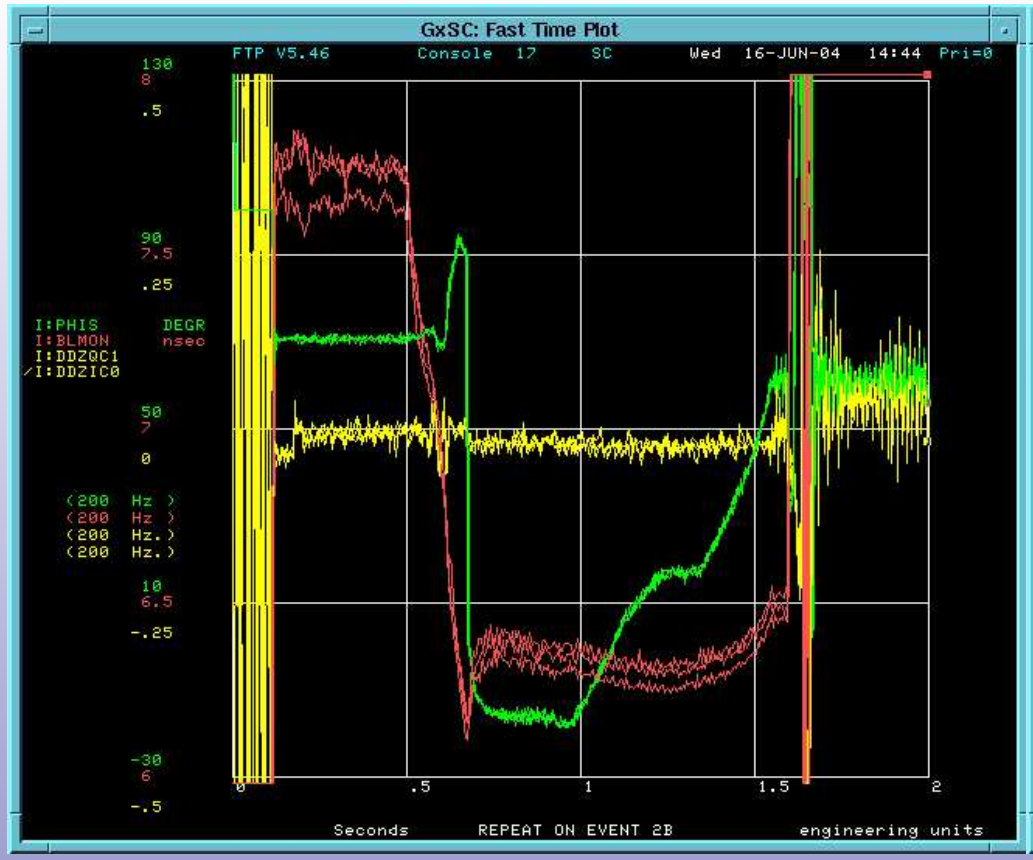

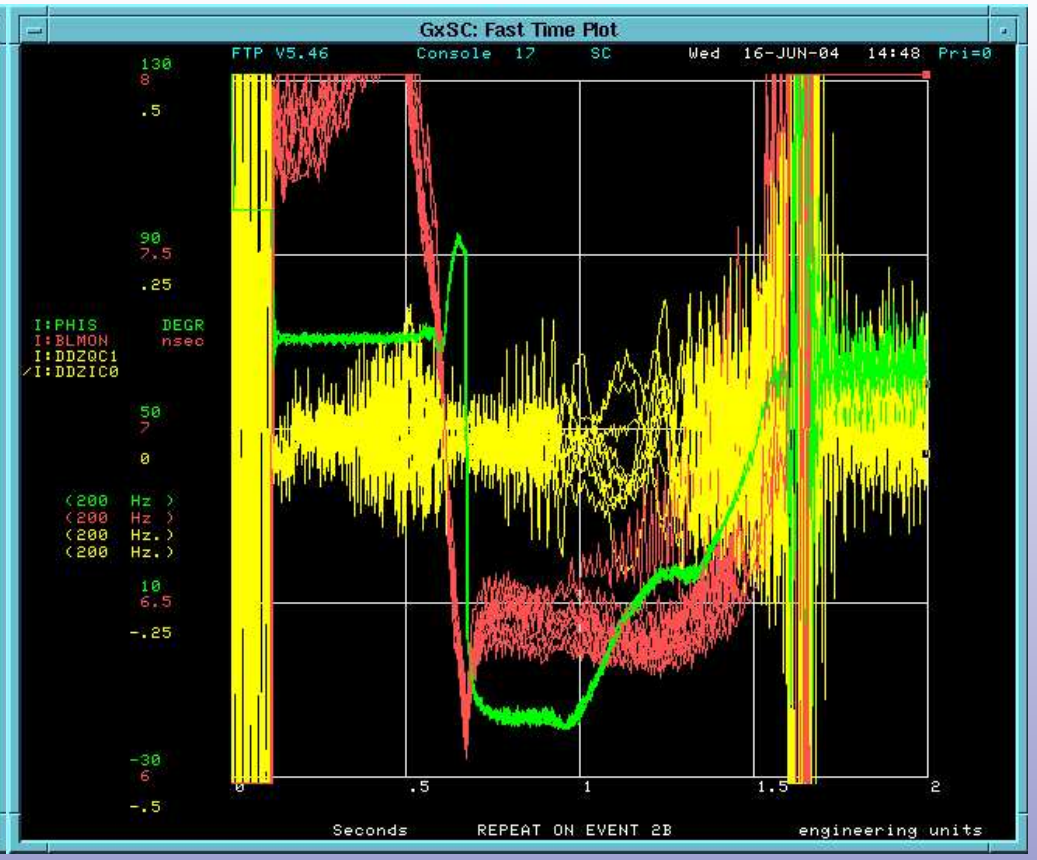

- Dampers on (left) and off (right) for a proton coalescing cycle
- Yellow trace: longitudinal phase of the middle 53 MHz bunch
- Longitudinal dampers give better coalescing efficiency and better longitudinal emmitance

NuMI multibatch

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- Transverse dampers enable chromaticity to be lowered
  - ⇒ Better 8 GeV lifetime

NuMI multibatch

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- Transverse dampers enable chromaticity to be lowered
  - ⇒ Better 8 GeV lifetime
- Without dampers, huge longitudinal oscillations build up
- NuMI needs stable, well-behaved beam to avoid irradiating the groundwater...

2.5 MHz studies

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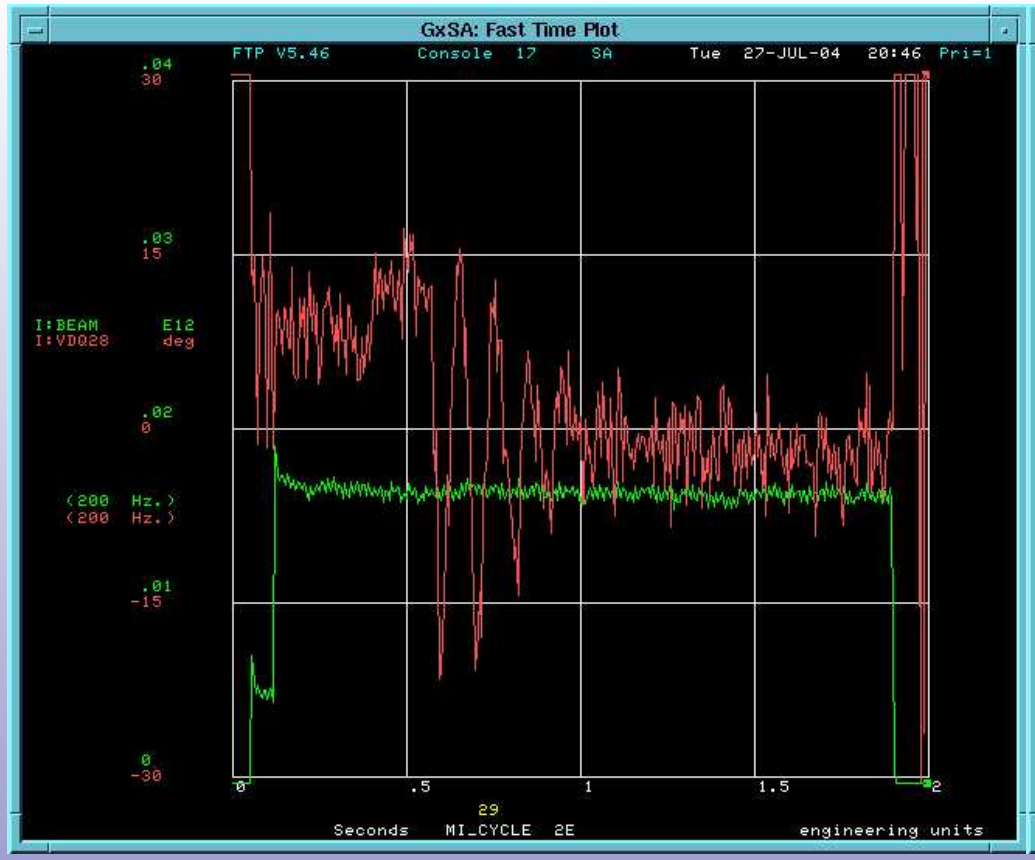
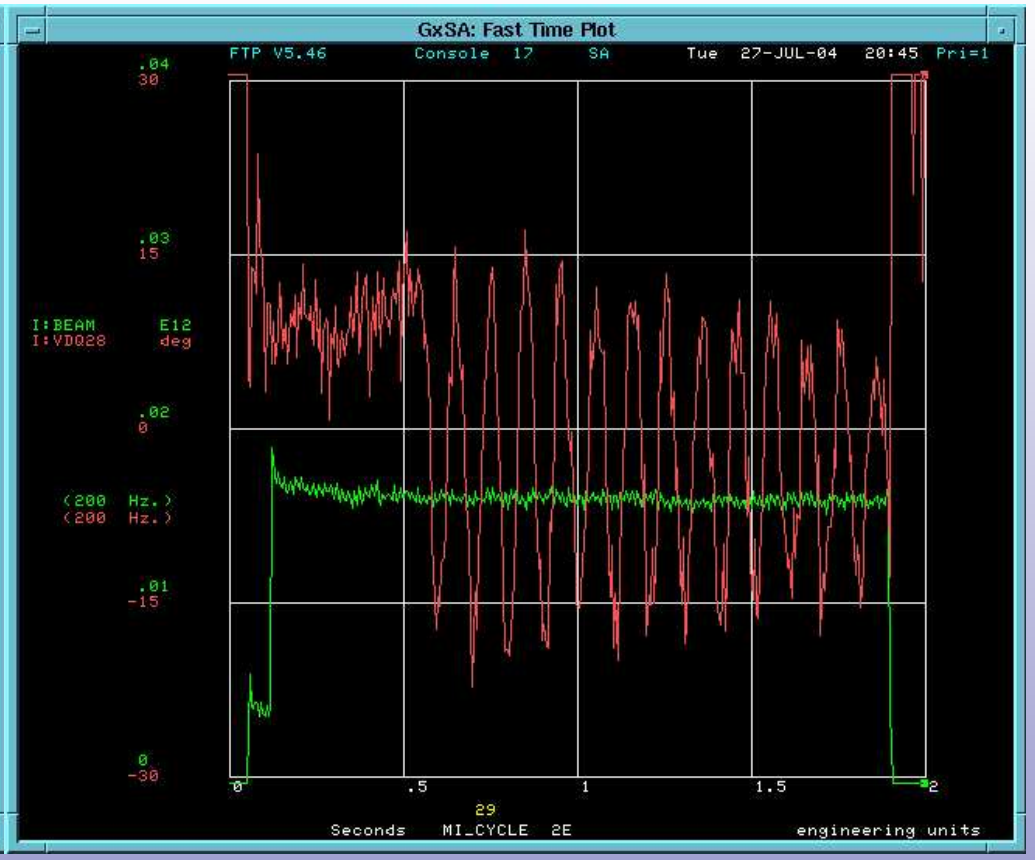


Dampers on (at 0.75 s)



Dampers off

2.5 MHz damping

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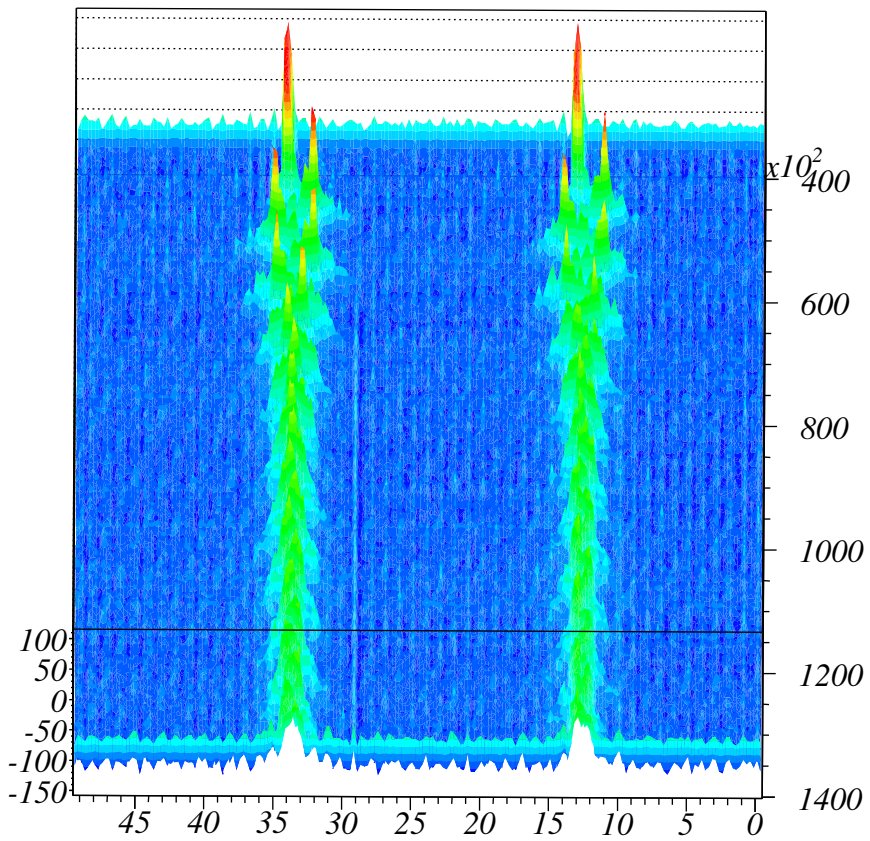

- Protons in 2.5 MHz...
- Turn on longitudinal dampers at turn 70,000
- Dipole oscillations damped
- Some quadrupole oscillations too

Pbar shots

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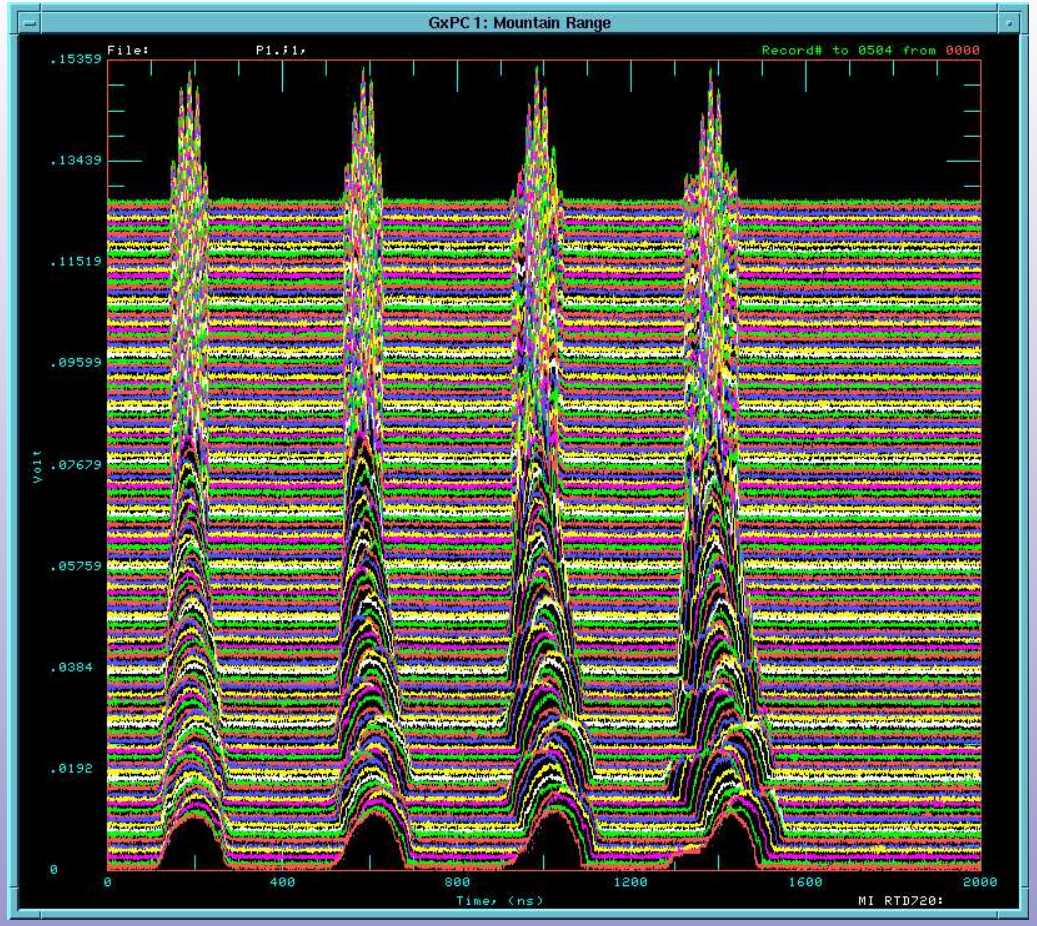

- Synchrotron oscillations in a pbar shot
- The last bunches are significantly worse, and end up having larger longitudinal emittances (2.6 eV s vs 2.1 eV s)
- Direct impact on luminosity
- The damper can fix this

Unfortunately...

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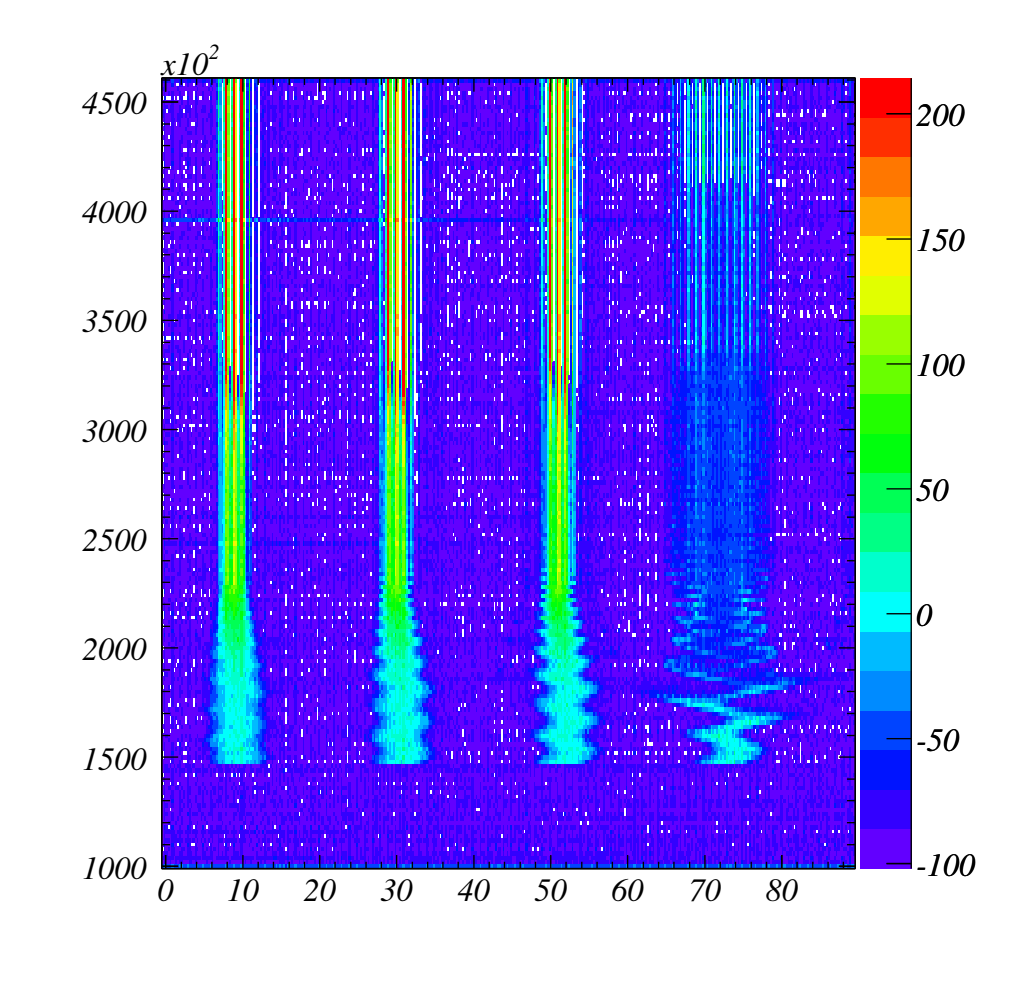
- We need to do a little more work
- Some timing issues to understand



Summary

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- Damper system is versatile & configurable
- Damping can help with essentially every MI cycle
- Good for luminosity, good for NuMI
- System still under heavy development
- Currently not user-friendly
- Non-expert application programs etc. over shutdown
- Fairly polished version ready for operator control at startup
- Also coming on the damper board: a tune meter for the MI.

Credits

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D. Nicklaus
A. Semenov
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