Bunch-by-bunch feedback demonstration in Solaris

D. Teytelman

Dimtel, Inc., San Jose, CA, USA

May 9, 2023

Demonstration Summary

- Monday, May 1:
  - Started from unpacking hardware already on site;
  - Set up the power amplifiers and the front-end prototype;
  - Traveled to the airport to pick up the rest of the hardware;
  - Set up transverse feedback in Y, then X.
- Tuesday, May 2:
  - Performed vertical calibration;
  - Explored an improvised setup with 13 dB more gain;
  - Collected open-loop, closed-loop, grow/damp, and excite/damp data in Y;
  - Started on the improvised longitudinal setup with 400 MHz iGp12 clock.
- Wednesday, May 3:
  - Completed longitudinal setup, demonstrated damping, collected some modal information;
  - Ultimately unsuccessful in controlling longitudinally unstable beam — too little power;
  - Continued with transverse feedback setup at 536 MeV and bunch cleaning.

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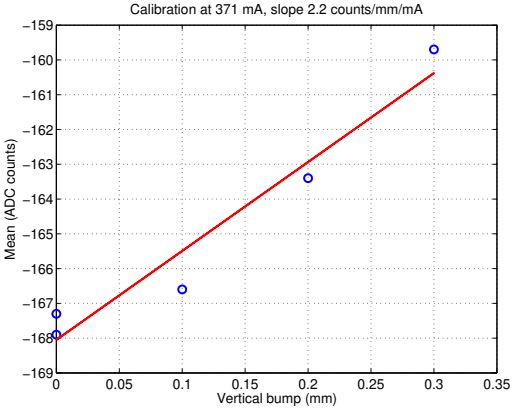

- Measure ADC mean shift with an orbit bump;
- Prototype front-end is at 400 MHz, relatively low sensitivity;
- At nominal bunch current one ADC count is 36 µm;
- We tested an improvised higher gain setup, roughly 9.8 counts/mm/mA;
- One count then corresponds to 8 µm.

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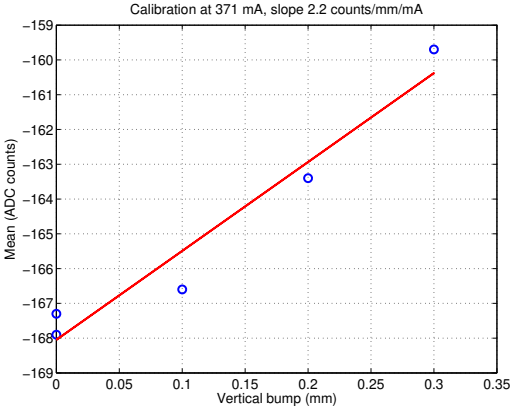

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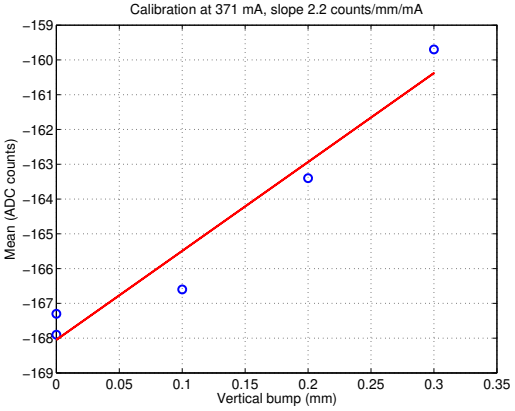

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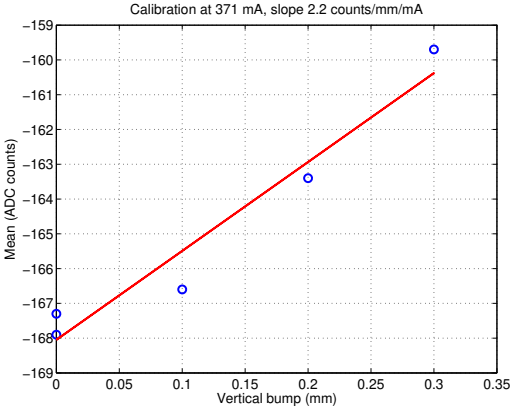

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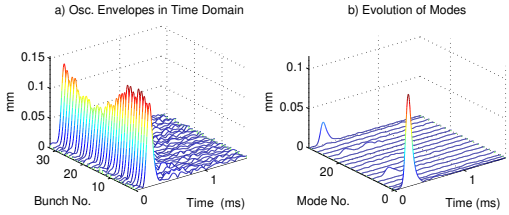
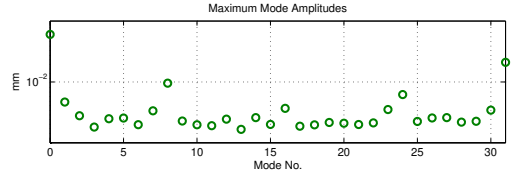
Vertical Plane with Pulsed Kicker



Solaris:may0223/140428: Io= 320mA, Dsamp= 1, ShifGain= 1, Nbun= 32,
At ν: G1= 12.5728, G2= 6.95, Ph1= −165.7718, Ph2= −151.7544, Brkpt= 392754, Calib= 9.827.



- Open-loop acquisition with the injection (?) kicker firing;
- 320 mA;
- Mode zero (all bunches moving together) and mode -1 (resistive wall) are excited;
- Main observation — very fast disappearance of the centroid signal;
- Signal re-appears (re-coherence) after approximately one synchrotron period;
- Consistent with high vertical chromaticity.

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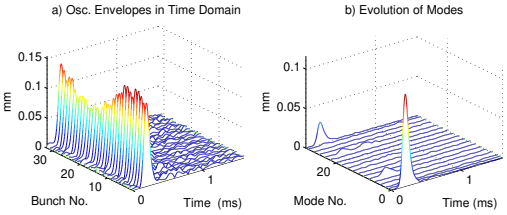

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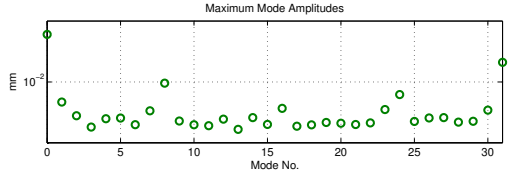

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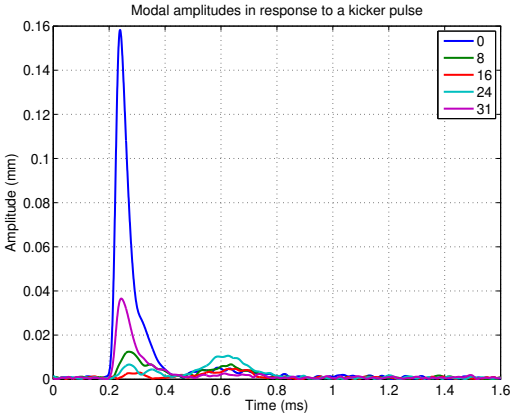

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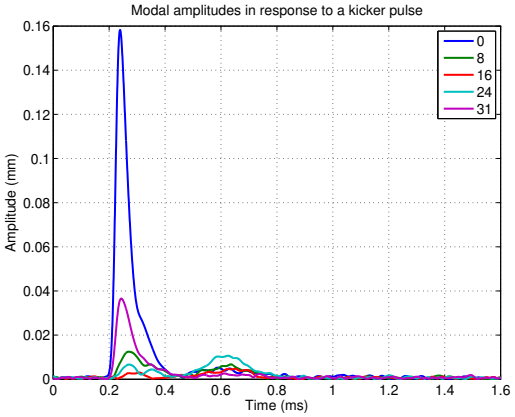

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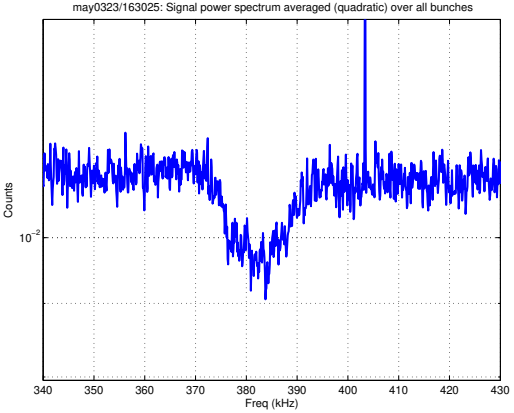
Closed Loop Spectrum Vertical Plane



- At 1.51 GeV and 350 mA;
- Typical notch due to feedback action — inverse of the beam response;
- Wide at high bunch currents, indicative of tune spreads and high damping;
- At lower currents see multiple notches at syncho-betatron sidebands in addition to the betatron line, consistent with high chromaticity.

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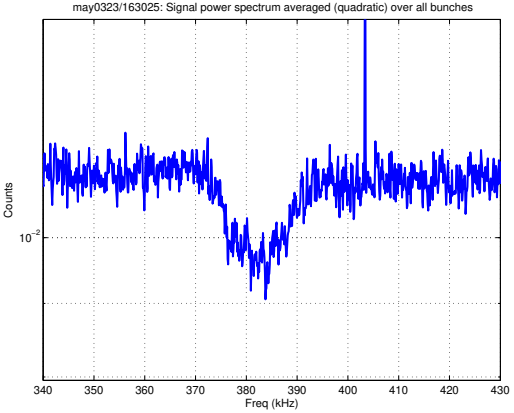

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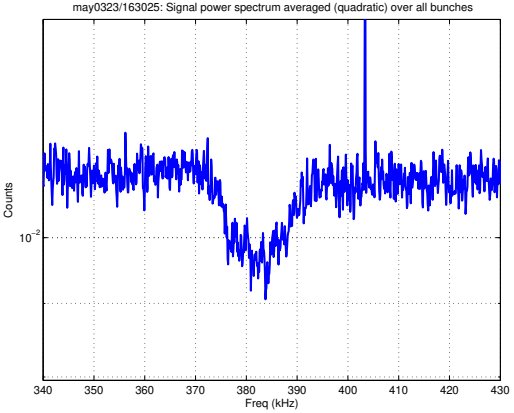

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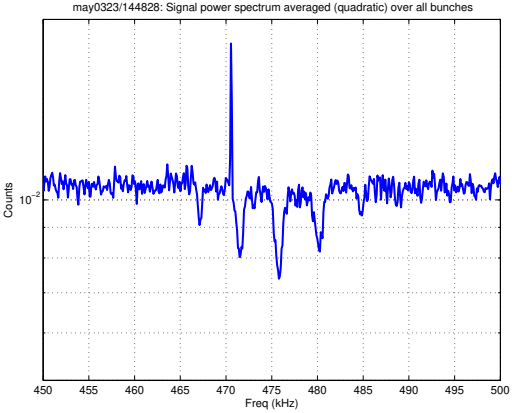

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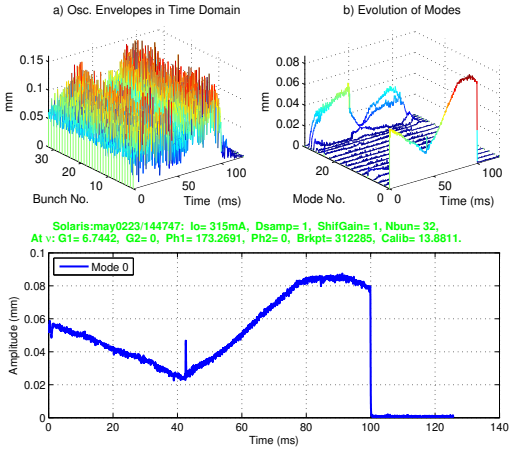

- Mode 0 excited in the closed-loop setting by frequency sweep of 10 kHz around the betatron tune;
- At 100 ms excitation and feedback are turned off;
- Vertical oscillation signal decays very quickly (64 μs damping time);
- Most likely the bunches decohere rapidly.

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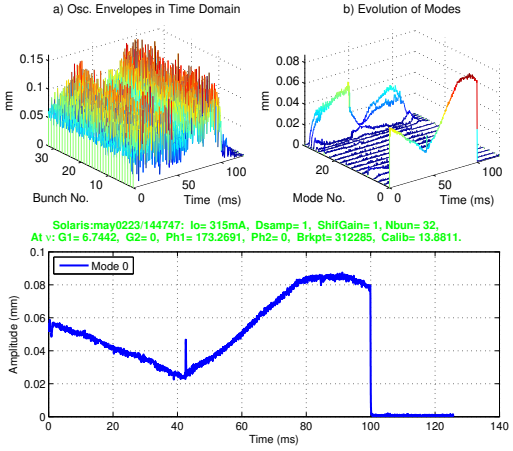

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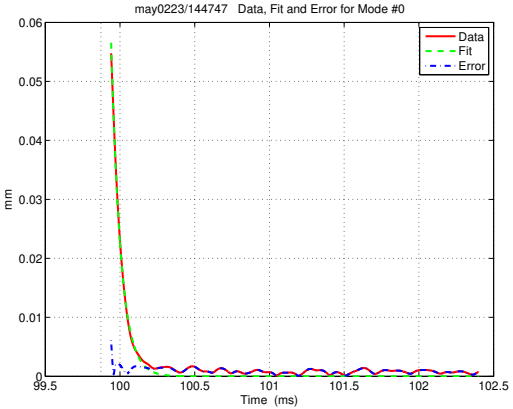

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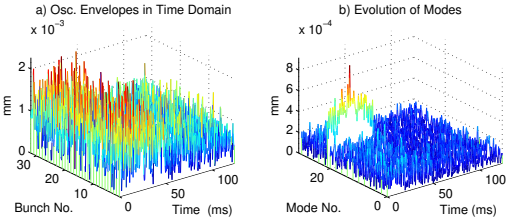

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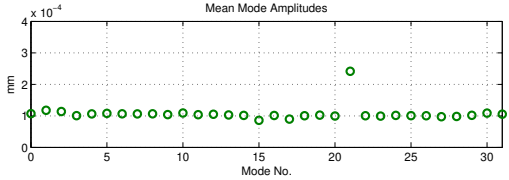

- True grow/damp measurement, feedback is off for 50 ms;
- See mode 21 (33.9 MHz);
- No growth dynamics, almost step change;
- Similar response with a 120 ms open loop period;
- Saturates around 0.5 µm;
- Need to be confirmed that this is real beam motion.

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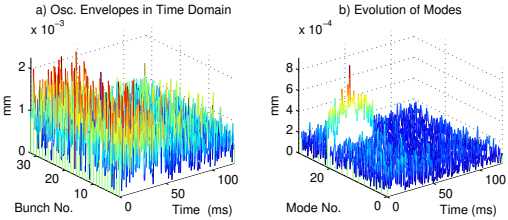

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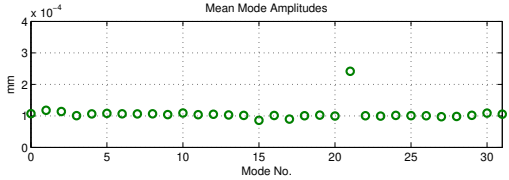

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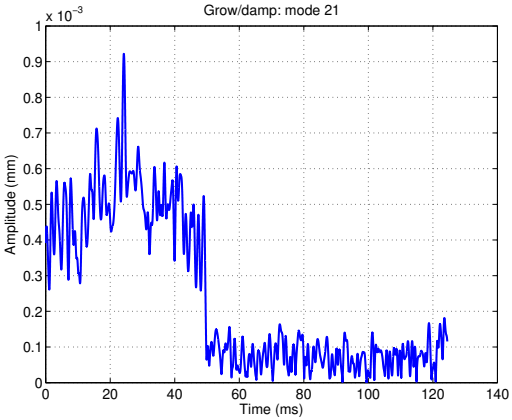

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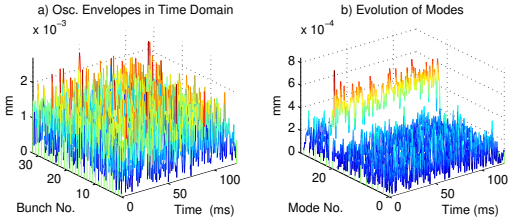

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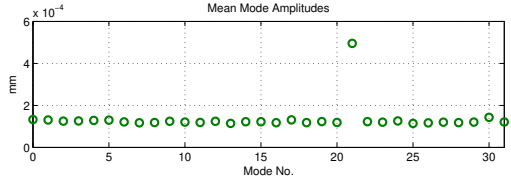

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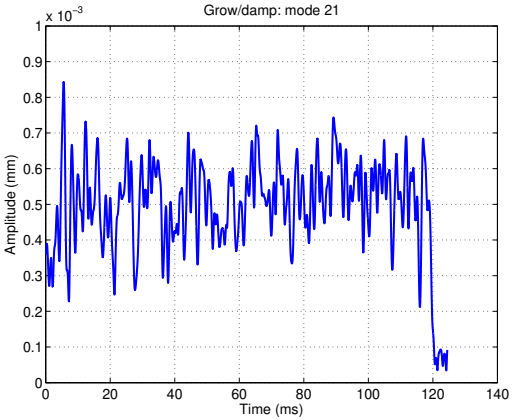

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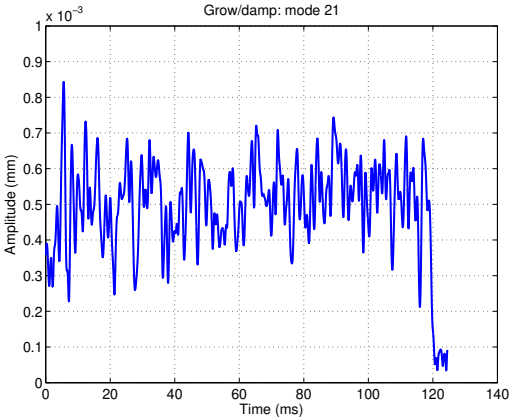

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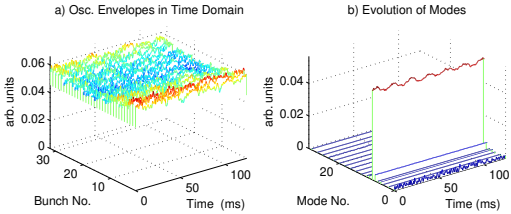

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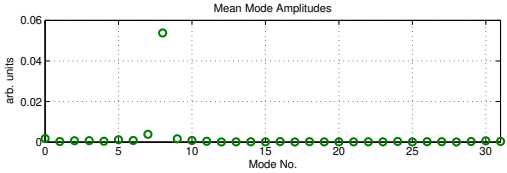

- Longitudinal instabilities are seen above $\approx$ 4 mA
- An example at 302 mA with harmonic cavities tuned in, mode 8;
- Lower current — mode 10.

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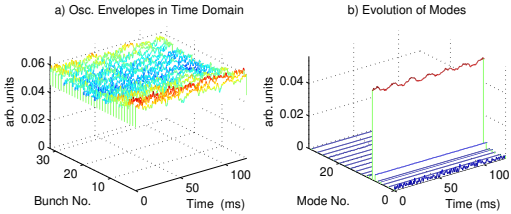

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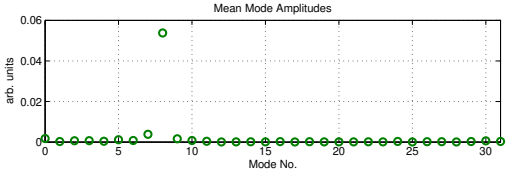

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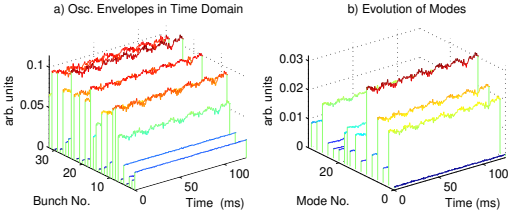

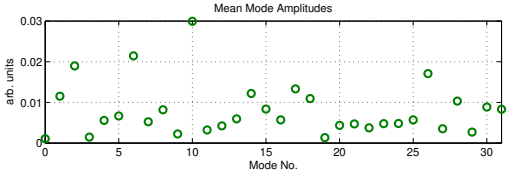

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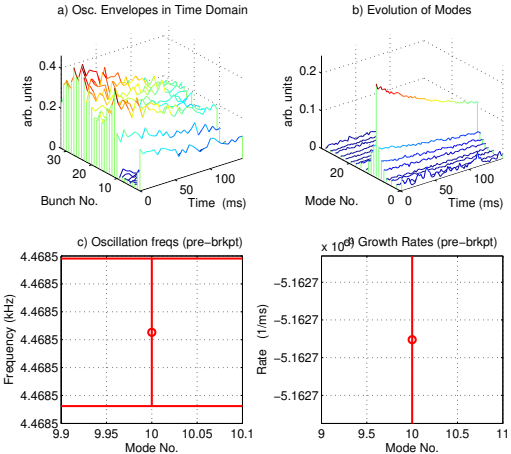

- The method:
  - Each mode is excited to a small amplitude using CW sinusoidal excitation;
  - In a transient measurement excitation and feedback are turned off;
  - Open-loop damping transient is analyzed to estimate the modal frequency and the damping rate.
- Mode 10 open loop;
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- Much faster damping;
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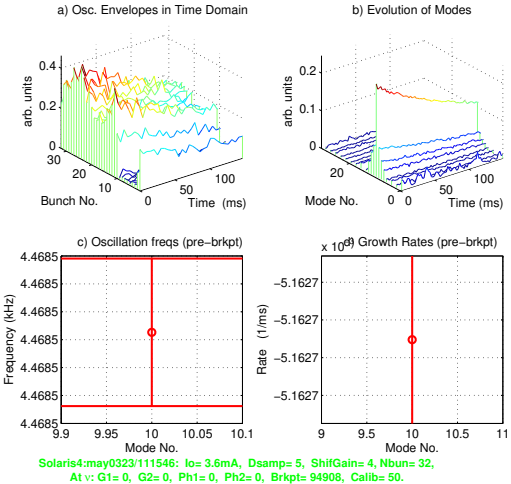

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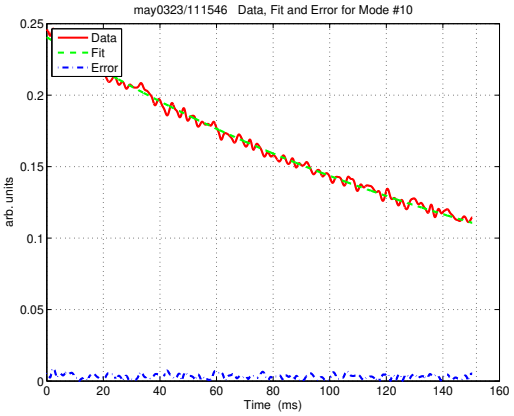

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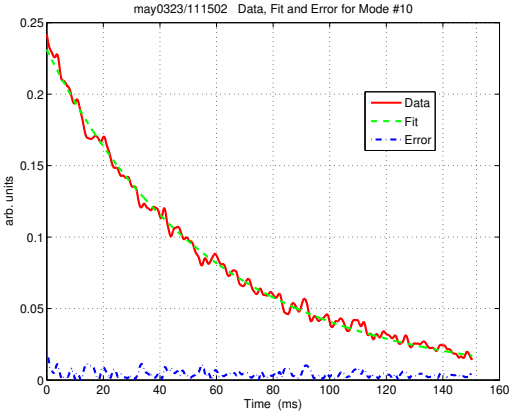

- The method:
  - Each mode is excited to a small amplitude using CW sinusoidal excitation;
  - In a transient measurement excitation and feedback are turned off;
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- Mode 10 open loop;
- Mode 10 closed loop;
- Much faster damping;
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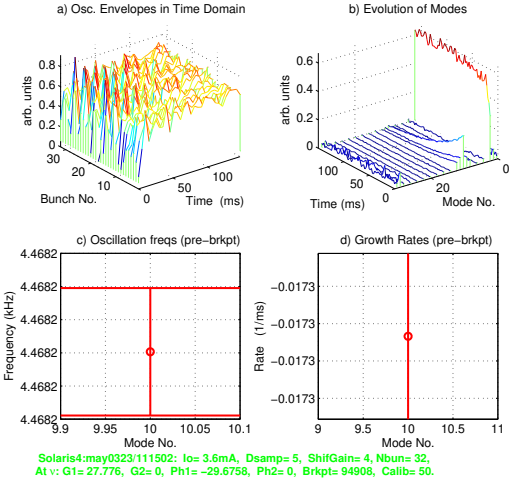

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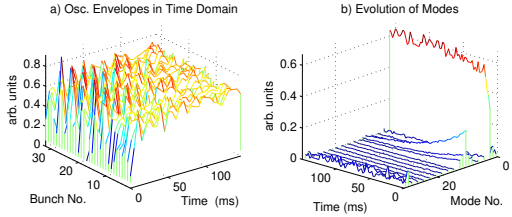

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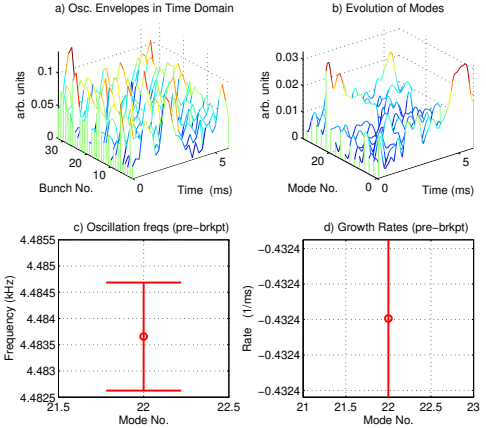
Damping Transients, Mode -10 (AKA 22)



- Physical impedance is Hermitian. If mode N is shifted towards instability, mode $h - N$ should see an almost identical shift in the opposite direction (damping);
- Mode 22 open loop;
- Open loop damping of 432 s^{-1};
- Mode 10 damps at 5 s^{-1};
- Average (radiation) damping of 218 s^{-1} (4.6 ms), impedance shifts ± 213 s^{-1}.
- Modal frequencies 4468 and 4484 Hz, reactive shifts of ± 50 rad s^{-1}.

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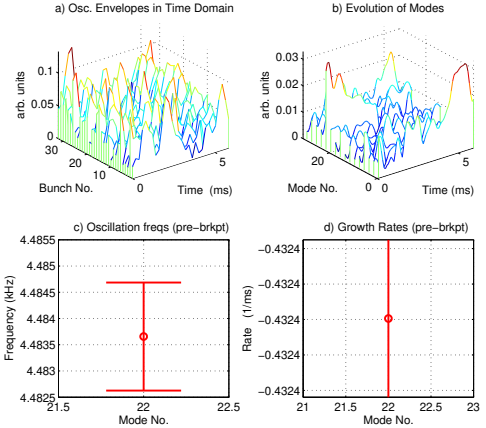

Solaris4:may0323/112707: Io= 3.6mA, Dsamp= 5, ShifGain= 4, Nbun= 32,
At ν: G1= 0, G2= 0, Ph1= 0, Ph2= 0, Brkpt= 3751, Calib= 50.

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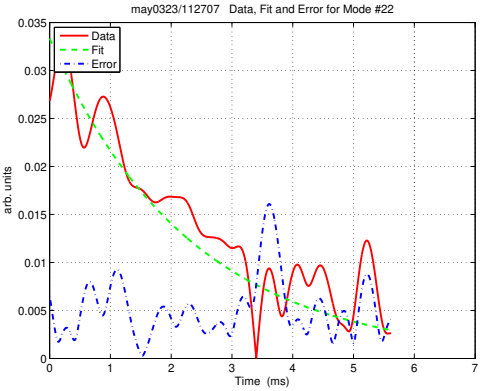

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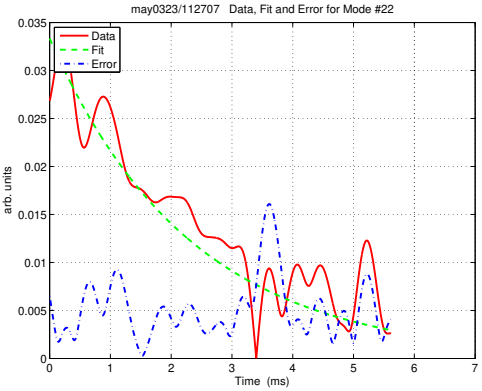

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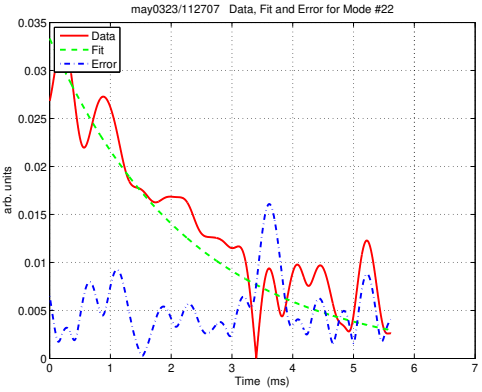

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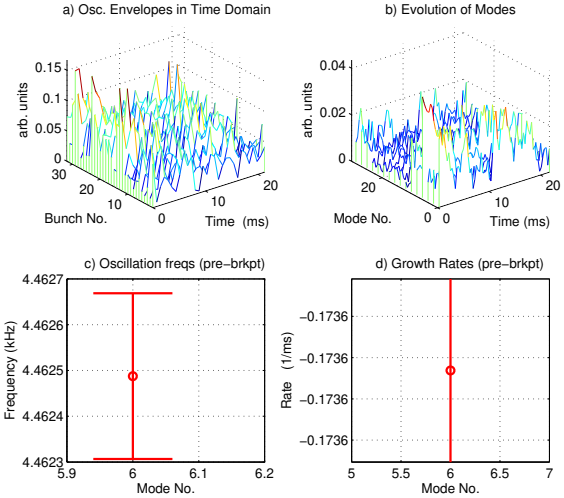
Damping Transients, Mode 6



Solaris4:may0323/112922: Io= 3.6mA, Dsamp= 5, ShifGain= 4, Nbun= 32,
At ν: G1= 0, G2= 0, Ph1= 0, Ph2= 0, Brkpt= 96286, Calib= 50.

- Mode 6, have not seen it unstable, possibly some impedance;
  - $\lambda_6 = -173 + i \times 2\pi 4462\ \mathrm{s}^{-1}$;
  - $\lambda_{10} = -5 + i \times 2\pi 4468\ \mathrm{s}^{-1}$;
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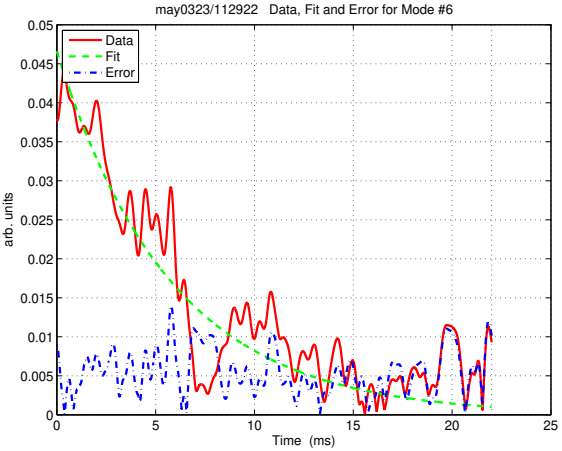

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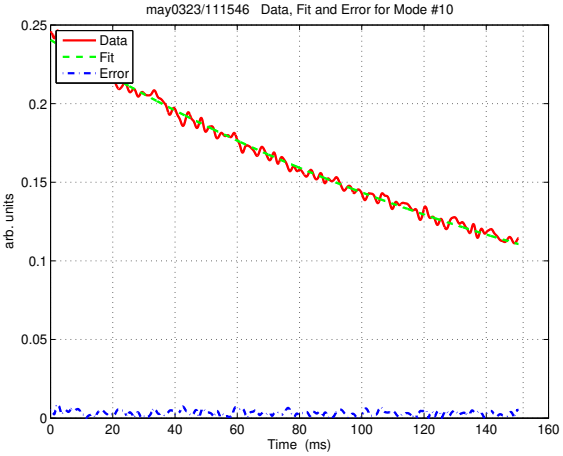

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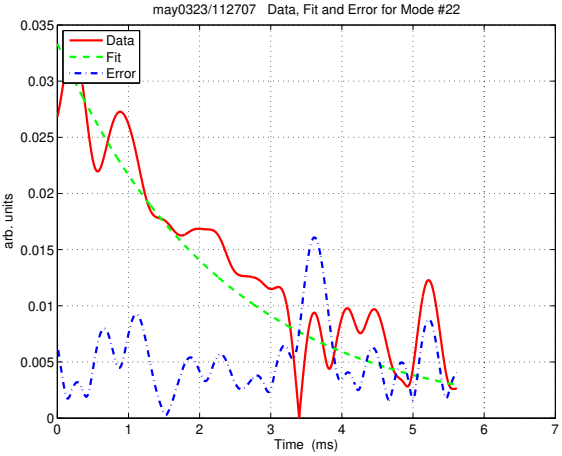

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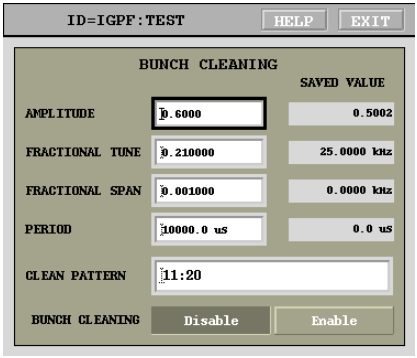
Bunch Cleaning



- Bunch cleaning is done by iGp12 as follows:
  - Apply normal negative feedback to the bunches we want to keep;
  - Turn off the feedback for the bunches to be removed;
  - Apply sinusoidal excitation with frequency sweeping to the bunches we are cleaning.
- Two power amplifiers (10 and 25 W) enable cleaning at the injection energy;
- An example of a fill pattern with a 5 bucket gap and a camshaft bunch in the middle (bunches 28,29,31,32 cleaned);
- Due to the synchronous phase transient amplitude detection is imperfect, here we re-center the detector.

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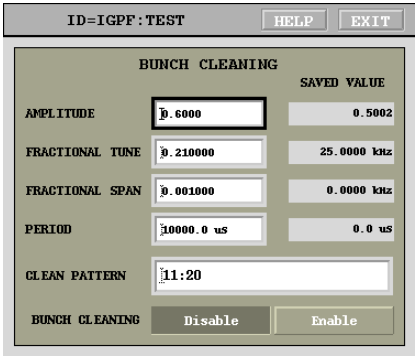

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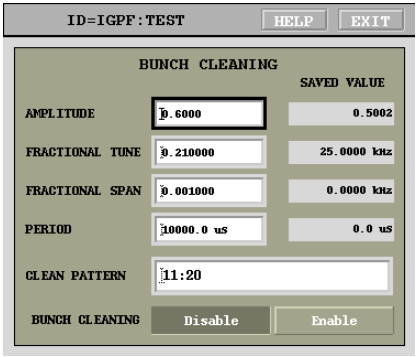

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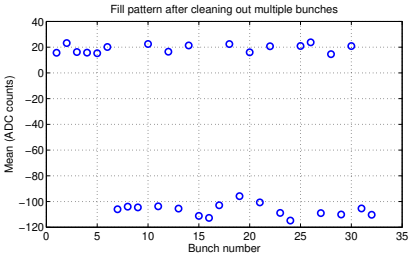

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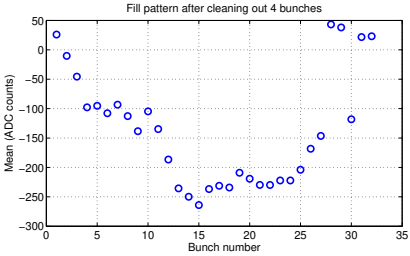

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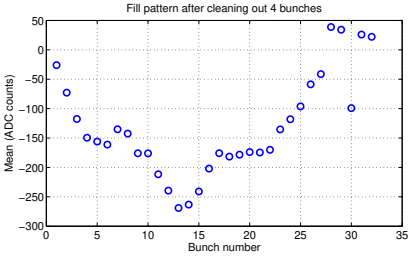

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Summary

- Demonstrated bunch-by-bunch feedback in all three planes;
- The beam is currently transversely stable at 400 mA;
- Transverse observations, both time and frequency domain, are consistent with high chromaticity in X and Y;
- Mode 21 in the vertical plane oscillates at 0.5 µm steady-state amplitude, observation to be confirmed;
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