

# Bunch-by-bunch Feedback Studies at SPEAR3

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July 2, 2010



# Outline

- 1 System overview
  - Introduction
  - Operating experience
  - SPEAR3 setup
- 2 Measurements
  - Calibration
  - Open-loop Measurements
  - Closed-loop Measurements
  - High Current Studies



# iGp Highlights



- A 500+ MHz processing channel.
- Finite Impulse Response (FIR) bunch-by-bunch filtering for feedback.
- Control and diagnostics via EPICS soft IOC on Linux.
- External triggers, fiducial synchronization, low-speed ADCs/DACs, general-purpose digital I/O.



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# Installed Units and Tests

## Commissioned systems

DAΦNE 4 systems, transverse;

ALS 1 system, longitudinal;

Photon Factory 3 systems, longitudinal and transverse;

Duke SR-FEL 2 systems, longitudinal and transverse;

CesrTA 3 systems, longitudinal and transverse;

BEPC-II 2 systems, longitudinal;

TLS 1 system, transverse;

Demonstrated in DELTA, ELSA, ANKA, MLS, KEKB.



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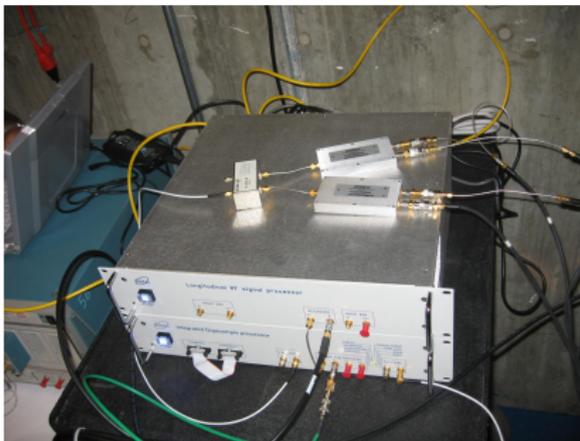
# Experimental Setup



- Three elements:
  - Front-end;
  - Baseband DSP;
  - Back-end.
- Modified ENI 525LA amplifier (25 W, 0.7-350 MHz);
- Tune excitation striplines;
- Passive front-end computes the difference of upper and lower buttons.



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# Experimental Program

- June 28, 2010

- Started hardware setup and parasitic timing one hour before the shift;
- At 5:55pm we completed the timing and captured a few parasitic data sets;
- Around 6:30pm we connected the power amplifier and started back-end timing;
- Loop closed at 8pm;
- Made a number of grow/damp measurements at 200 mA, explored chromaticity dependence.

- June 29, 2010

- Continued the measurements during high-current studies (400–450 mA);
- Stabilized the beam in both vertical and horizontal planes;
- Calibrated front-end sensitivity.



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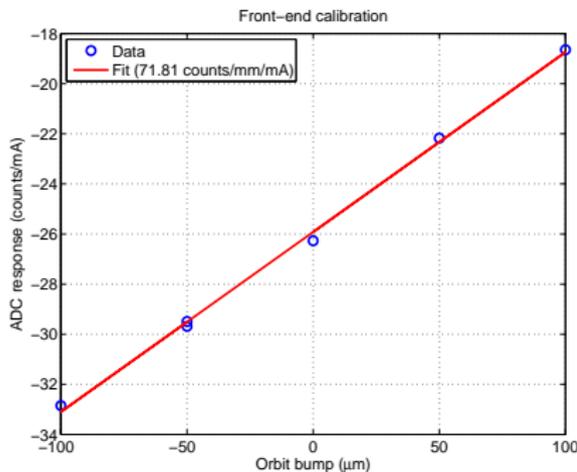


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# Front-end Calibration



- Set up orbit bumps near the feedback BPM;
- ADC signal for bunch  $n$  is  $V_n = g_{fe} \times y_n \times i_n$ ;
- Computed front-end gain of 71.8 counts/mm/mA.

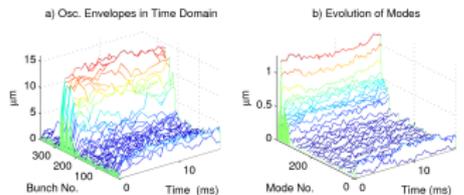


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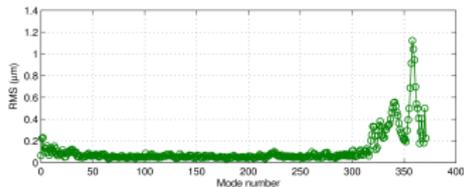
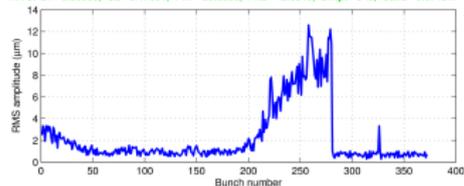


# Single Bunch Train



SPEAR3-jun2810/190017: Io= 199mA, Dsamps= 1, ShiftGain= 0, Nbu= 372,

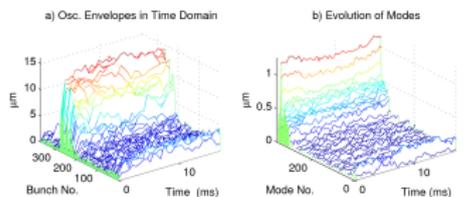
AI Fs: G1= 0.68036, G2= 0.17361, Ph1= 29.6206, Ph2= 42.0549, Brkpt= 343, Calib= 0.07181.



- First open-loop data set taken at 18:00;
- Bunches 1–280 and 326 are filled;
- Vertical coupled-bunch oscillations are seen;
- Oscillation amplitude rises along the bunch train;
- Several peaks in the modal spectrum, centered at 18 and 41 MHz.

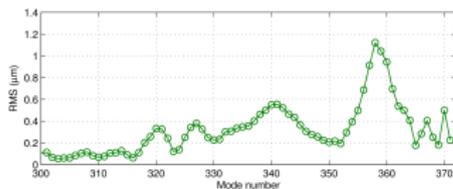
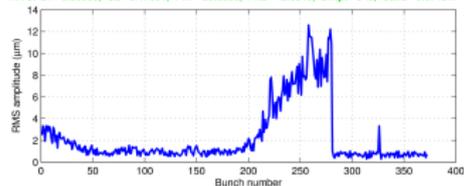


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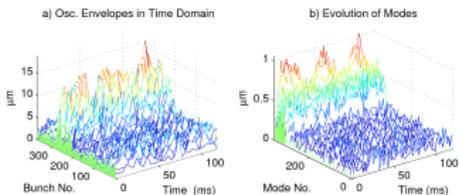
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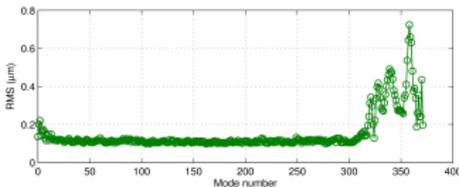
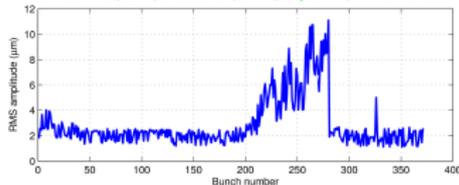
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# Single Bunch Train (Continued)



SPEAR3: jun2610/213753: Ios=199.5mA, Dsamp=7, SHHGains=4, Nbunch=372,  
At Fs: G1=26.2773, G2=0, Ph1=-41.7757, Ph2=0, Brkpts=18956, Calib=0.07181.

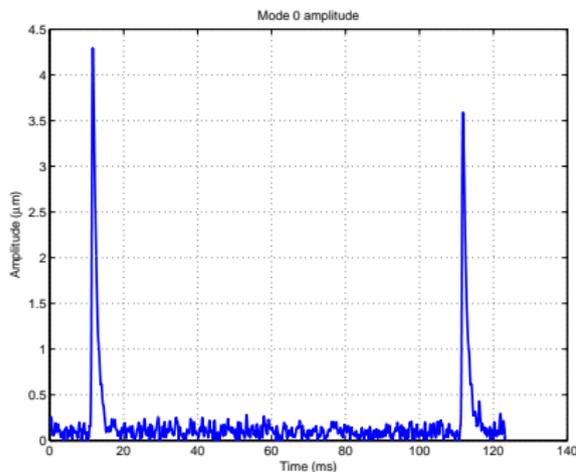


- Same fill pattern, longer (120 ms) data set;
- Amplitudes of modes centered at 18 MHz (mode 358 or -14) are beating at roughly 25 Hz;
- Modal spectrum is the same as in the short set.





# Injection Transients



- 120 ms record acquired during injection;
- Amplitude of mode 0 (all bunches move in phase) shows injection transients;
- Can extract information on injection bump closure from such measurements.

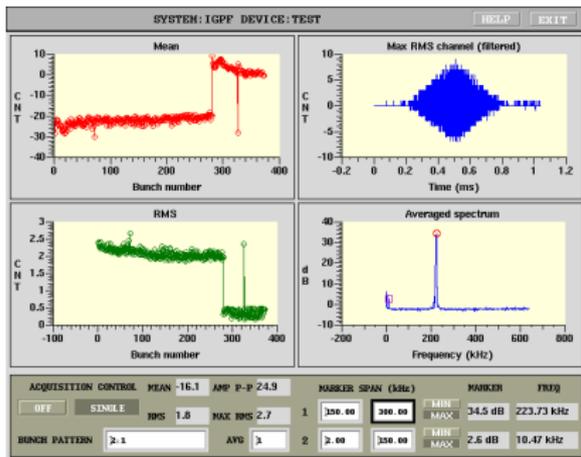


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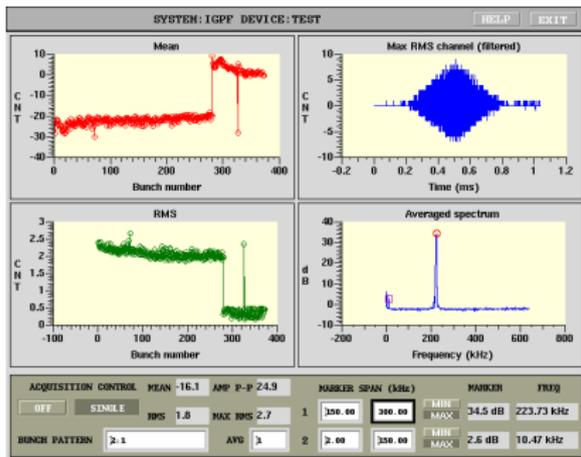
# Waveform Panel



- Updates at 1 Hz
- Uses data from all bunches over many turns.
- Four waveforms:
  - Mean;
  - RMS;
  - Bunch with largest RMS;
  - Averaged spectrum of all bunches.



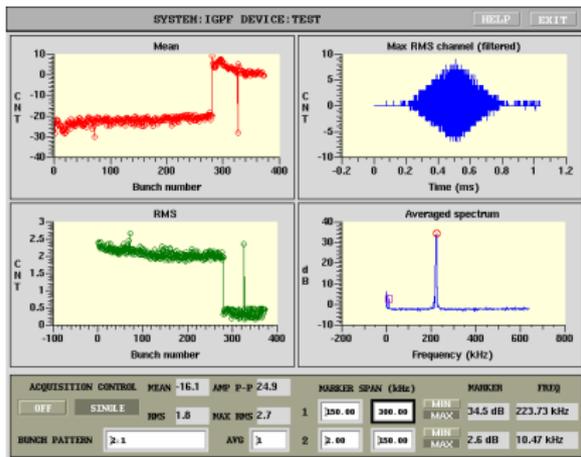
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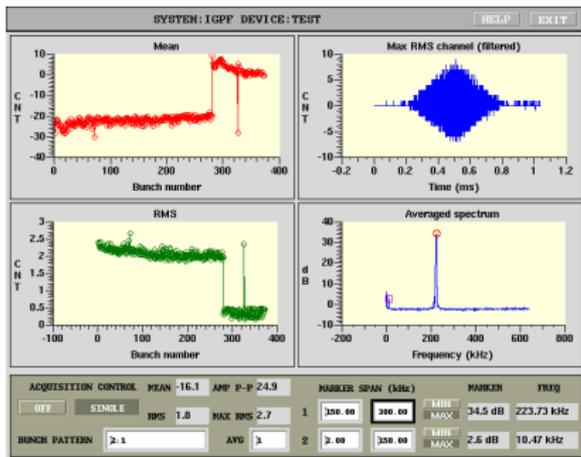
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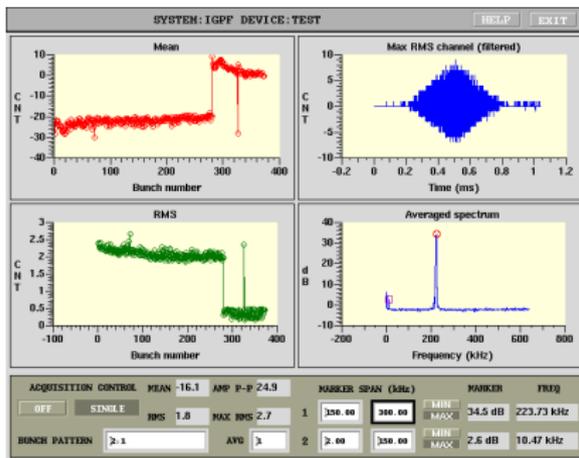
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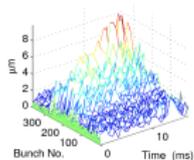


- Drive/damp measurement;
- Feedback is positive for first 450  $\mu$ s, then negative;
- Clearly exciting the beam;
- Large betatron line in the spectrum at 223.7 kHz

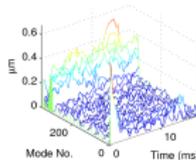


# Grow/Damp Measurement

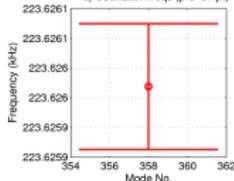
a) Osc. Envelopes in Time Domain



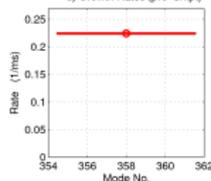
b) Evolution of Modes



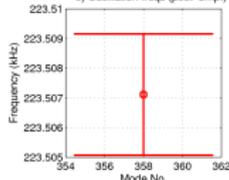
c) Oscillation freqs (pre-brkpt)



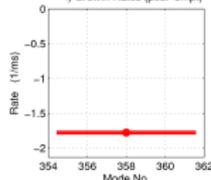
d) Growth Rates (pre-brkpt)



e) Oscillation freqs (post-brkpt)



f) Growth Rates (post-brkpt)

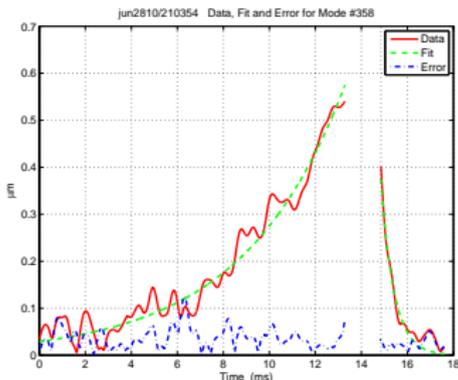


SPEAR3-jun2010216354: I0= 199.5mA, Dsamp= 1, ShfGain= 4, Nbu= 372.  
At Fs: G1= 27.0058, G2= 0, Ph1= -14.953, Ph2= 0, Brkpt= 19000, Calib= 0.07101.

- Grow/damp measurement at 200 mA;
- Very good damping of low-frequency modes;
- Feedback somewhat reactive — tune shift of 120 Hz between open and closed-loop;
- Growth rate of  $0.22 \text{ ms}^{-1}$ , damping rate of  $1.8 \text{ ms}^{-1}$ .

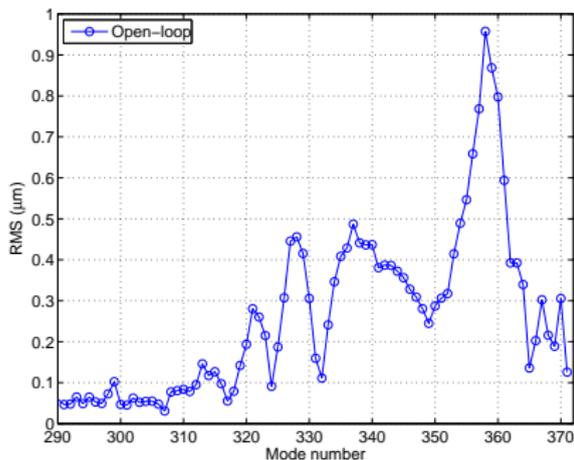


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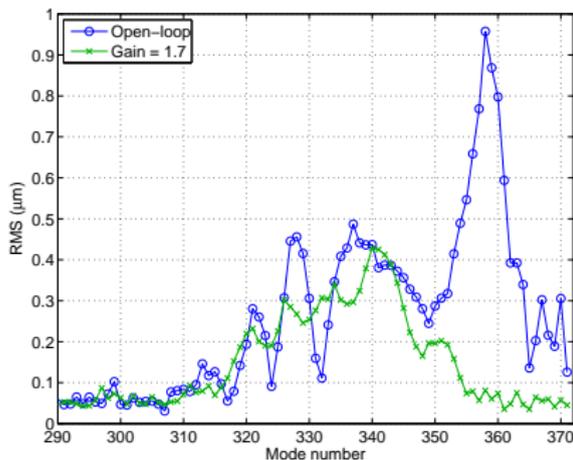
# Closed-loop Motion vs. Feedback Gain



- Open-loop measurement; ;
- Feedback on — damping 17 modes;
- Increase the gain — 15 more modes are damped;
- Double the gain — little change;
- Stripline bandwidth is around 20 MHz;
- With proper setup we can roughly double the control range.



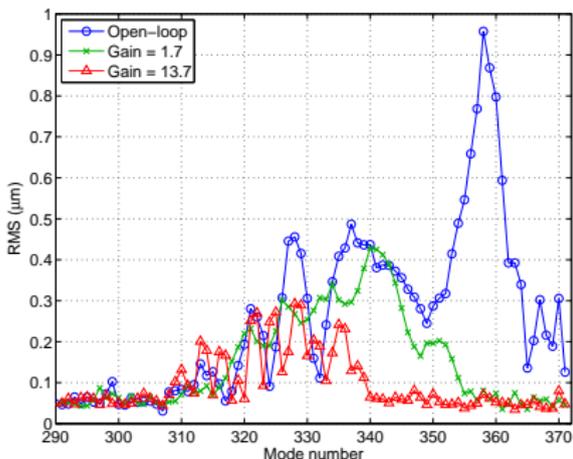
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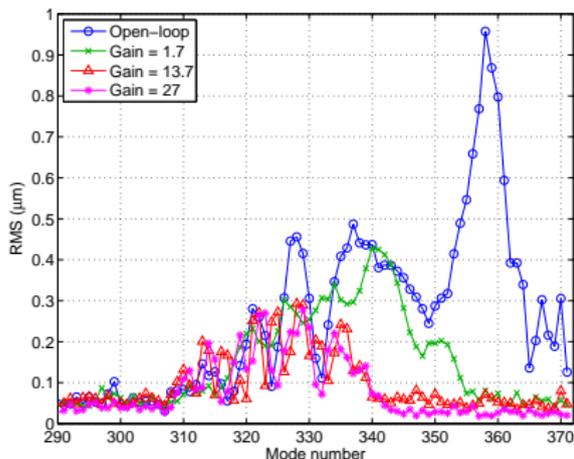
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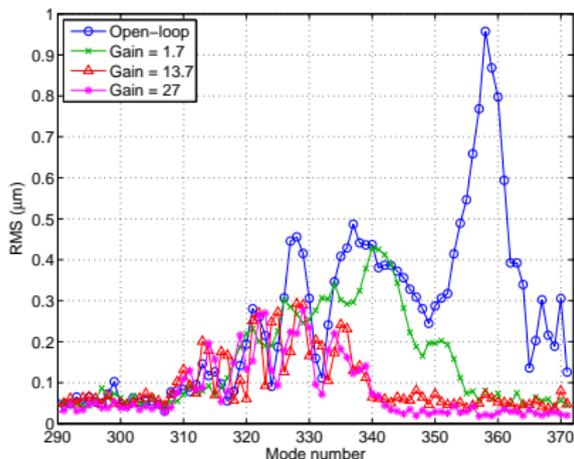
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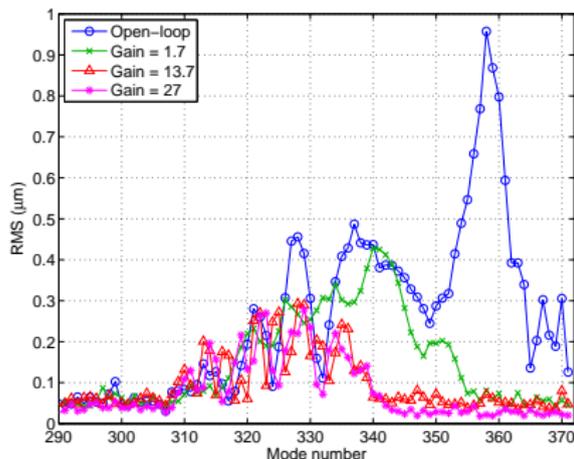
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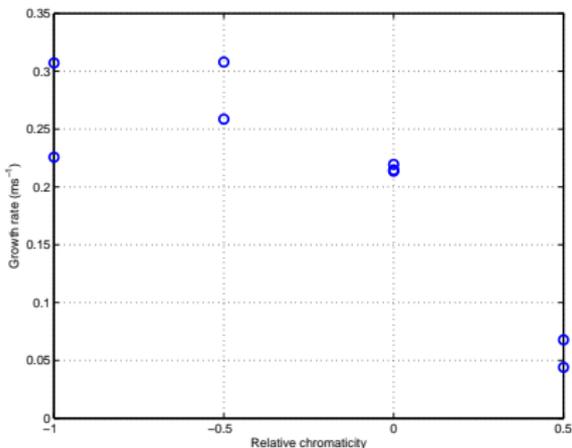
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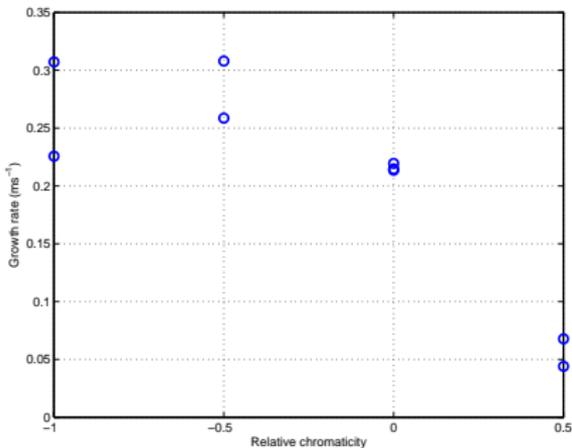
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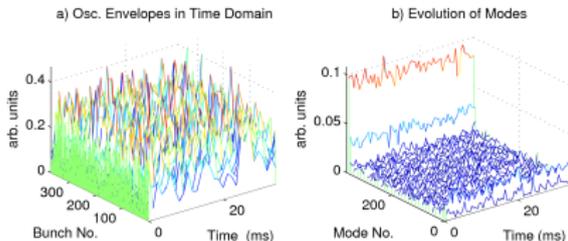


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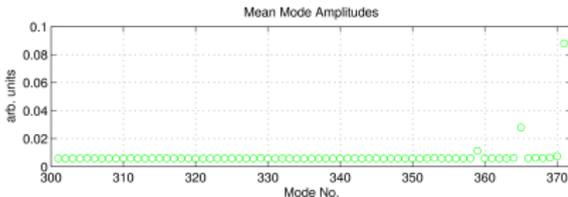
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# Horizontal Instabilities



SPEAR3:Jun2910/115450: Io= 448mA, Dsamp= 2, ShfGain= 0, Nbun= 372,  
At Fs: G1= 0.7299, G2= 0, Ph1= -127.588, Ph2= 0, Brkpt= 18956, Callb= 1.

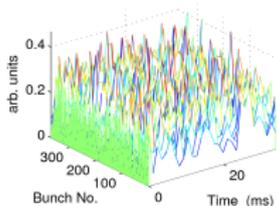


- Open-loop measurement: horizontal plane; ;
- Mode -1 — typical resistive wall motion;
- Vertical plane is dominated by mode 354 (-18).

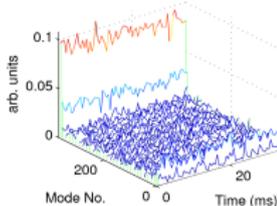


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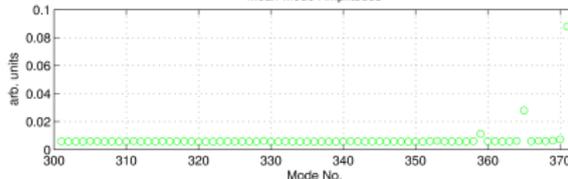
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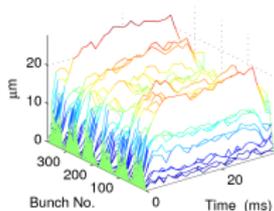
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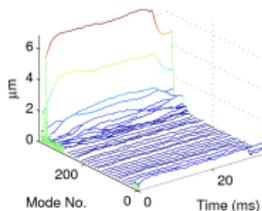


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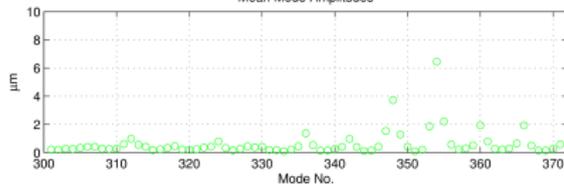
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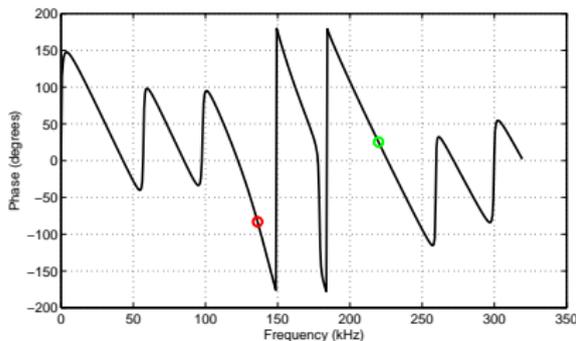
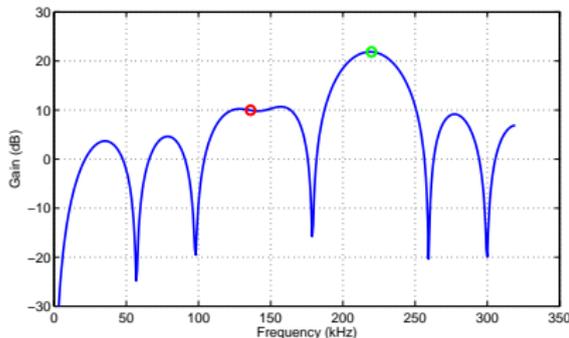
SPEAR3:jun2910/115450: Ie= 448mA, Dsamp= 2, ShiftGain= 0, Nbun= 372,  
AI Fs: G1= 0.14417, G2= 0, Ph1= -114.1356, Ph2= 0, Brkpl= 18956, Calib= 0.07181.

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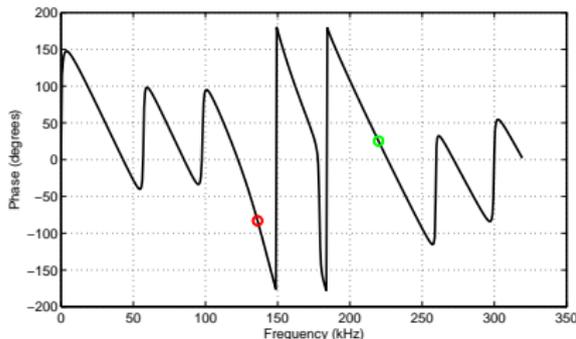
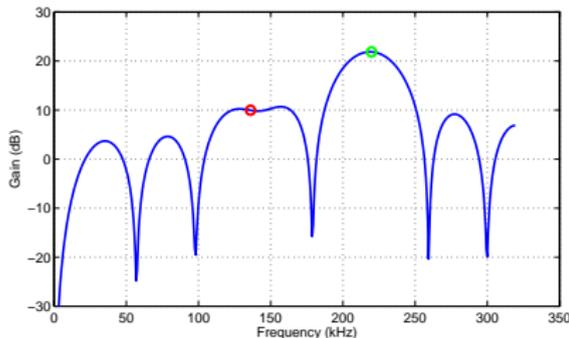
# Dual-Band Filter



- Created a dual-band filter with negative feedback response in both horizontal and vertical planes;
- Matlab tool generates filter coefficients matching desired gains and phases at the two betatron tunes;
- Fully suppressed horizontal motion.



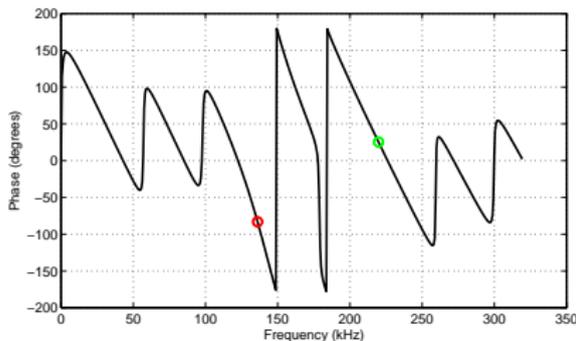
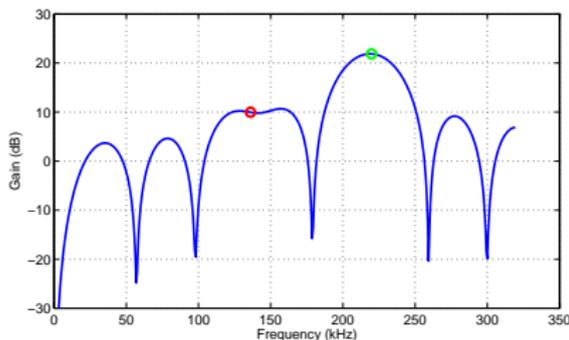
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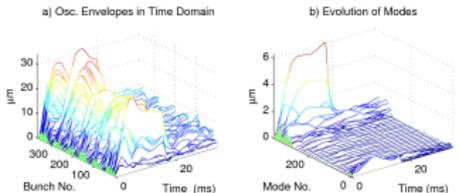
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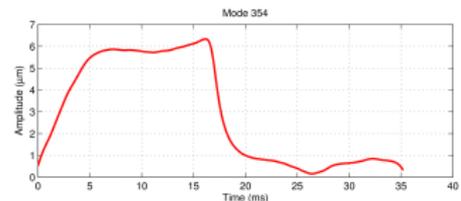
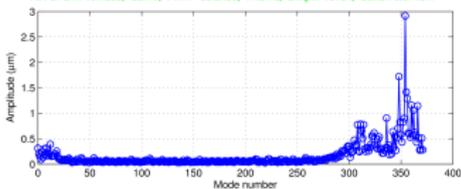
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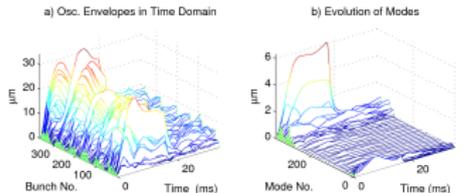
SPEAR3-jun0910/124617: Ip= 448mA, Damp= 2, ShifGain= 1, Nbu= 372, At Fs: G1= 10.1282, G2= 0, Ph1= -35.2436, Ph2= 0, Brkpts= 10724, Calib= 0.07181.



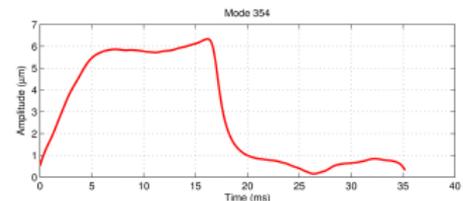
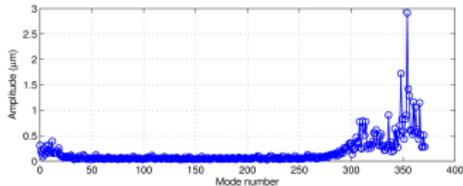
- Six trains of 47 bunches separated by 15 bunch gaps; ;
- Open-loop amplitudes reach 35  $\mu\text{m}$ ;
- Non-exponential growth — consistent with smaller fill-pattern gaps.



# Vertical Grow/Damp



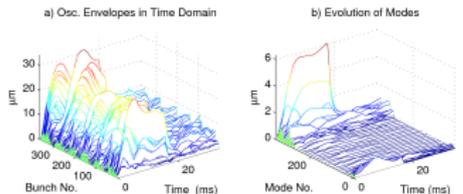
SPEAR3-jun0910/124617: Ip= 448mA, Dsmp= 2, ShifGain= 1, Nbu= 372,  
At Fs: G1= 10.1282, G2= 0, Ph1= -35.2436, Ph2= 0, Brkpts= 10724, Callb= 0.07181.



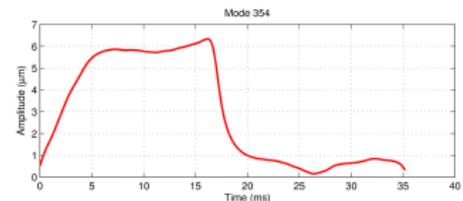
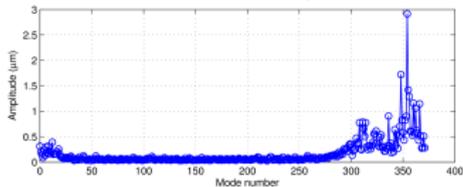
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At Fs: G1= 10.1282, G2= 0, Ph1= -35.2436, Ph2= 0, Brkpts= 10724, Callbe= 0.07181.



- Six trains of 47 bunches separated by 15 bunch gaps; ;
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# Summary

- We have successfully demonstrated feedback control of transverse coupled bunch instabilities in SPEAR3.
- There is strong evidence of ion-driven instabilities in the vertical plane at 200 mA and above;
- Resistive wall instabilities in the horizontal plane show up around 450 mA;
- We have demonstrated diagnostic capabilities of the iGp and correlated the measurements with existing instrumentation;
- Further measurements would benefit from better striplines and amplifiers.



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