Bunch-by-bunch Feedback Commissioning at the HLS

Zhou ZeRan[1], J. Byrd, D. Teytelman[2], et. al.

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August 1, 2014

Outline

Work Summary

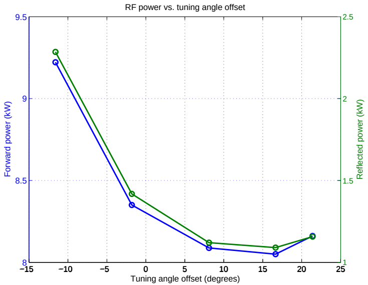
- Updated all 3 iGp12 units to the latest gateware/software release;
- Performed timing offset calibrations, should simplify future updates;
- Built an interface cable to enable monitoring of longitudinal power amplifiers (forward/reflected power, fault, RF state).

Outline

1. Setup
   - System Updates

2. Beam Studies
   - Single Bunch Stability
   - Longitudinal Instabilities
   - Possible Impedance Sources
   - Uneven Fills
     - Longitudinal Measurements
     - Vertical Measurements
     - Lifetime

Robinson stability



- Cavity tuning loop — reflected power is minimum at 15 degrees tuning angle;
- Main RF cavity tuning was Robinson unstable, limited single bunch current to 11 mA, 15 mA at the new angle;
- At 40 mA forward power minimum is at 0 degrees — measurement of cavity forward phase rotates with current?

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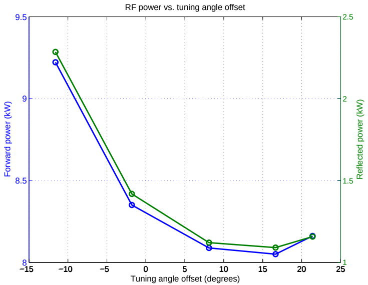

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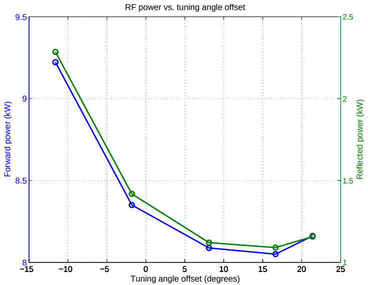

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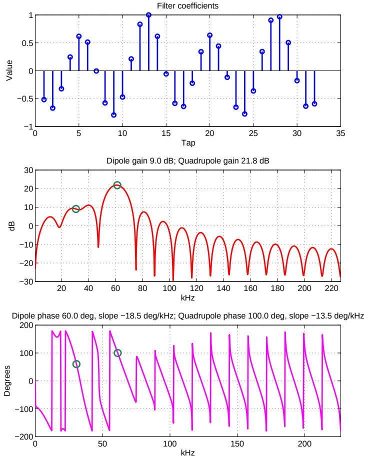
General Situation



- We see strong longitudinal coupled-bunch instabilities at very low beam currents (5–10 mA);
- Both dipole and quadrupole;
- Long bunch in the HLS → can act on quadrupole instabilities;
- Dual band feedback filter is tailored to provide appropriate gains and phases at synchrotron and quadrupole frequencies.

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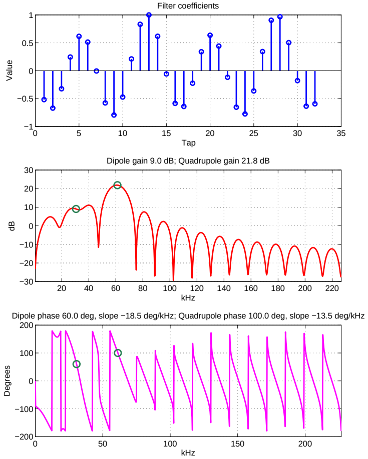

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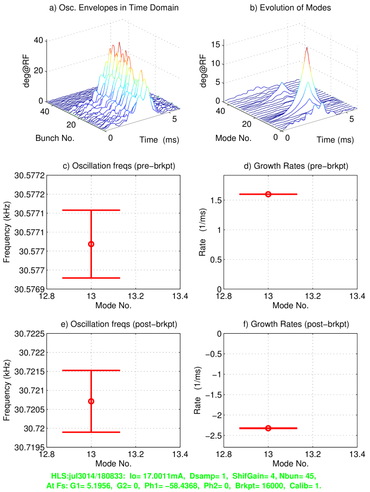
Dipole Grow/Damp



- Very fast growth rates for dipole instabilities;
- See eigenmode 13 — $N \times f_{\mathrm{RF}} + 58.9$ MHz;
- Excellent fit to growth and damping.

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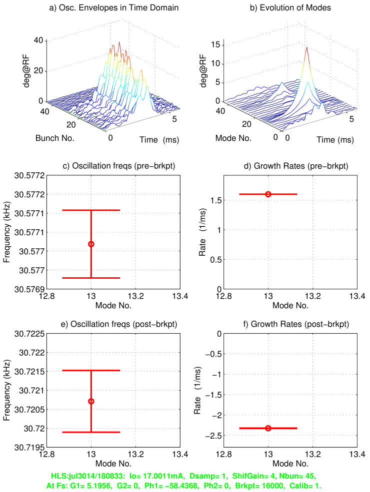

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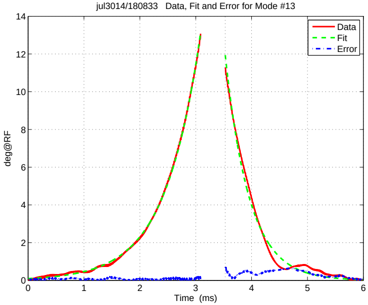

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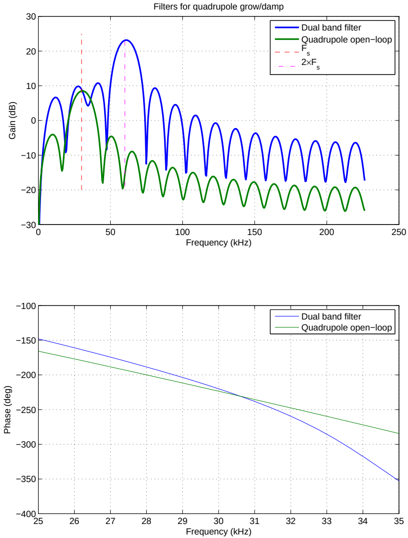

- A filter to notch out quadrupole feedback;
- Nice growth and damping of quadrupole oscillation;
- Textbook exponential growth;
- At the same time, dipole motion is fully suppressed.

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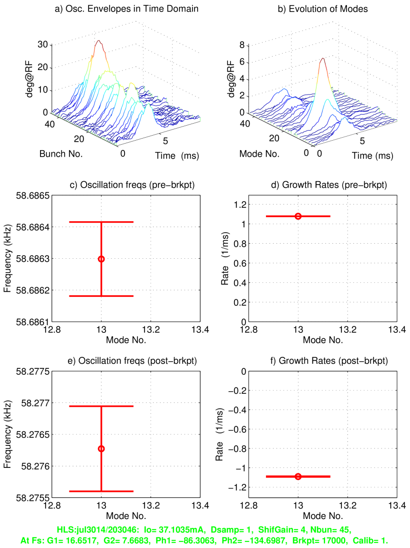

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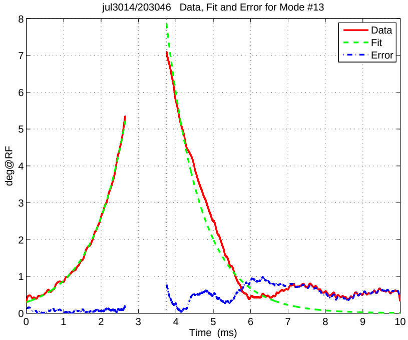

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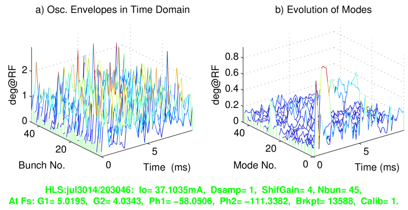

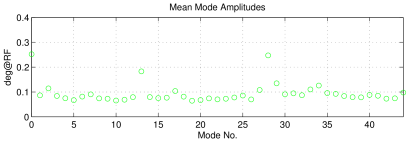

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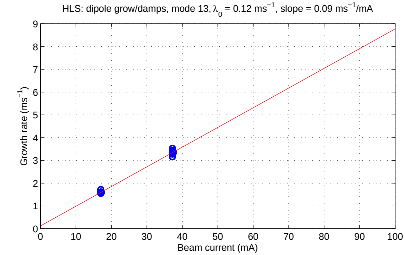
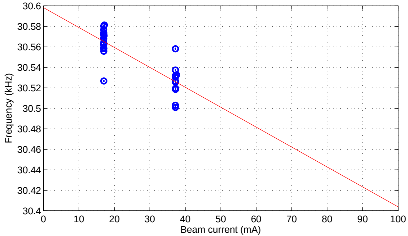
Dipole Growth Rates vs. Beam Current





- Steep slope, at 100 mA growth time of 4 synchrotron periods;
- July 31 measurements in an even fill;
- Estimated effective impedance of 232 kΩ.

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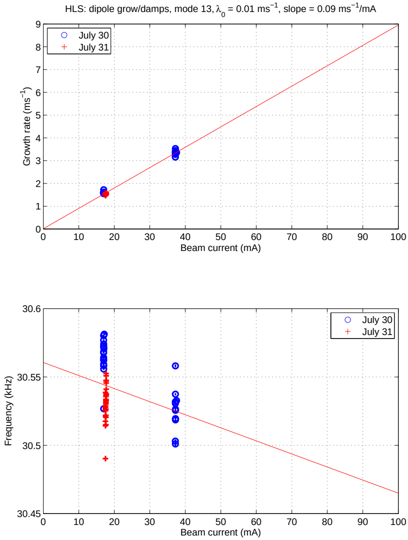

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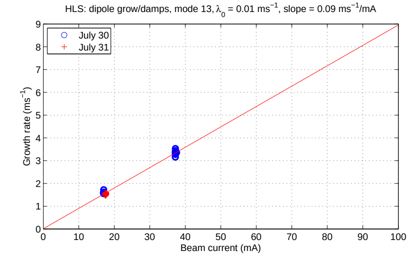

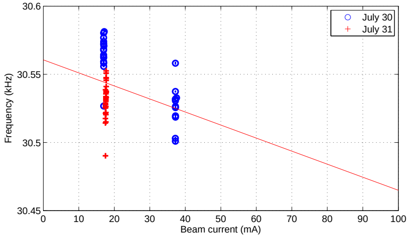

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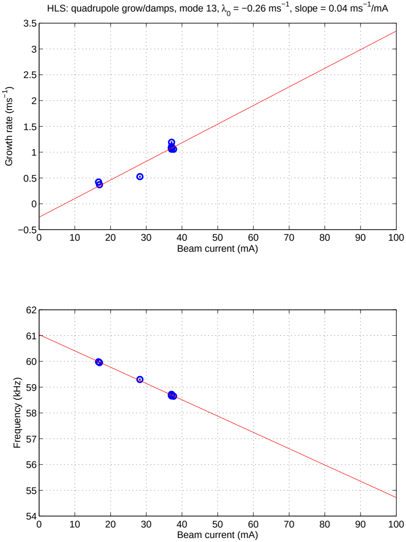

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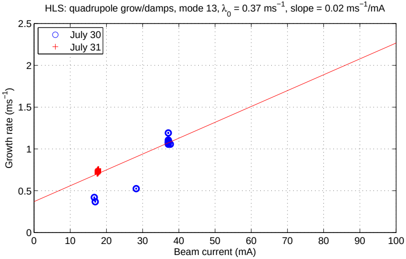

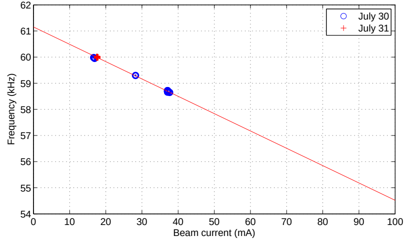

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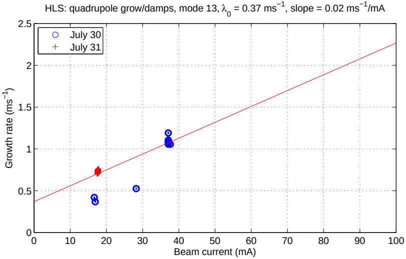

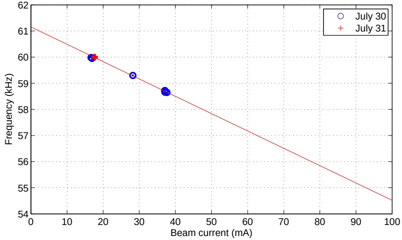

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Driving Impedance Discussion

- Very fast growth rates of dipole mode (1.5 ms^{-1}) at 20 mA multibunch (even-fill pattern) implies large narrowband impedance;
- Very fast growth rates of quadrupole mode (0.75 ms^{-1}) at 20 mA multibunch (even-fill pattern) implies large narrowband impedance;
- We spent some time looking for sources:
  - Main RF
  - Harmonic RF
  - Other unknown resonant structure

Driving Impedance Discussion Continued

- Large narrowband impedance also implies possible strong heating
  - cavities are water-cooled
  - no other significant vacuum activity observed correlated with HOM heating (using special fill pattern to excite 13$^{\text{th}}$ revolution harmonic)
- Main RF cavity
  - no strong resonance observed in main cavity probe corresponding to observed beam mode 13 ($N \times f_{\mathrm{RF}} + 13 \times f_{\mathrm{rev}}$)
  - significant HOM activity observed in coaxial feed to main cavity. Unusual but no evidence linking it to instabilities.
- Other structures (LFB, TFB kickers; striplines, etc.)
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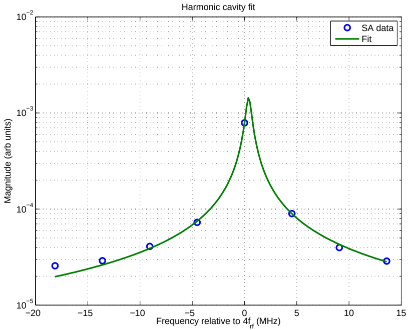
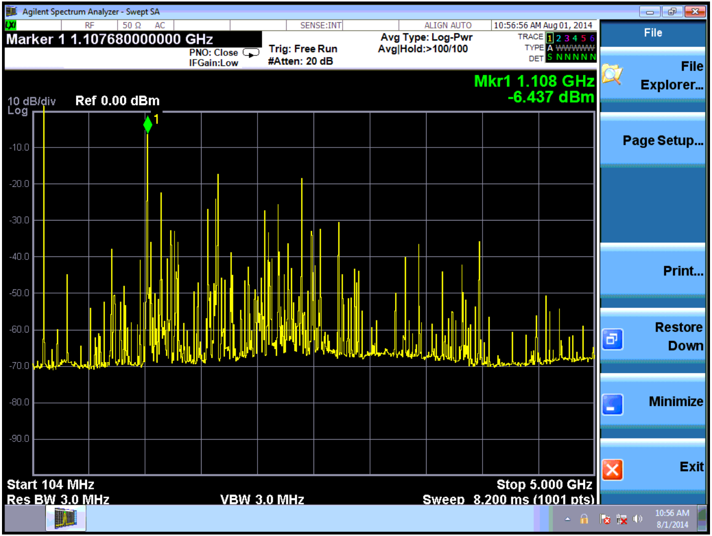
Harmonic Cavity



- Observed single fundamental mode. No HOMs!
- Magnitudes of revolution harmonics $\rightarrow$ estimate cavity ω_r and Q.
- Tuned 392 kHz above $4 \times f_{\mathrm{RF}}$, $Q = 1600$.

Forward Power Coupler, Main RF



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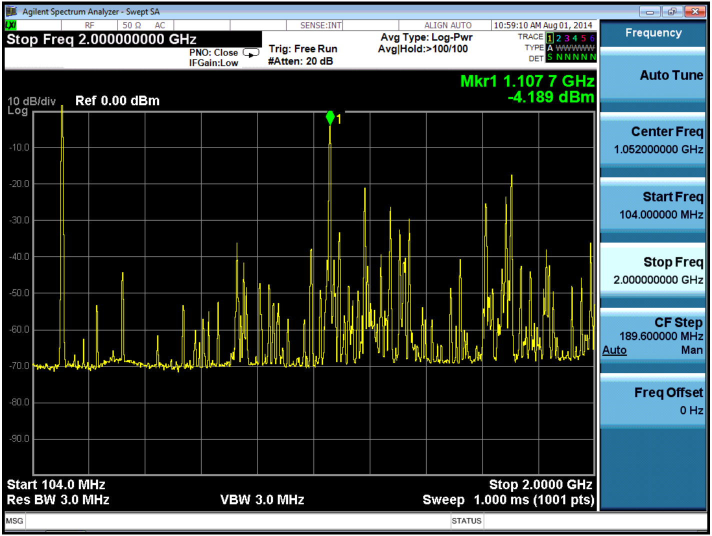
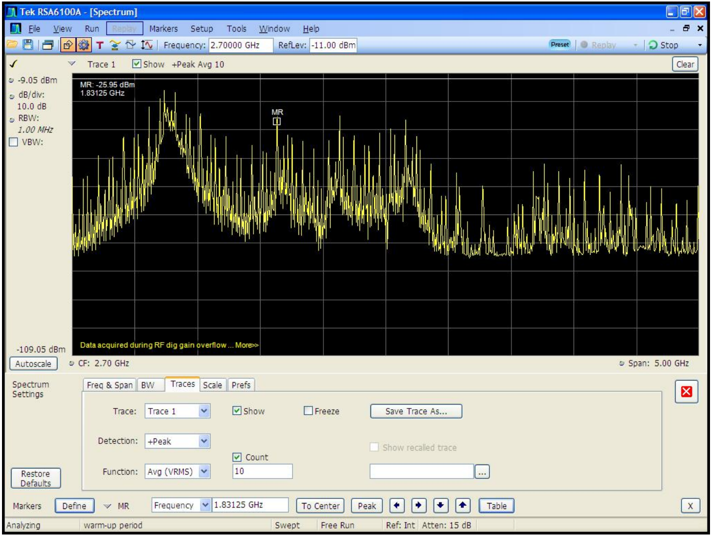
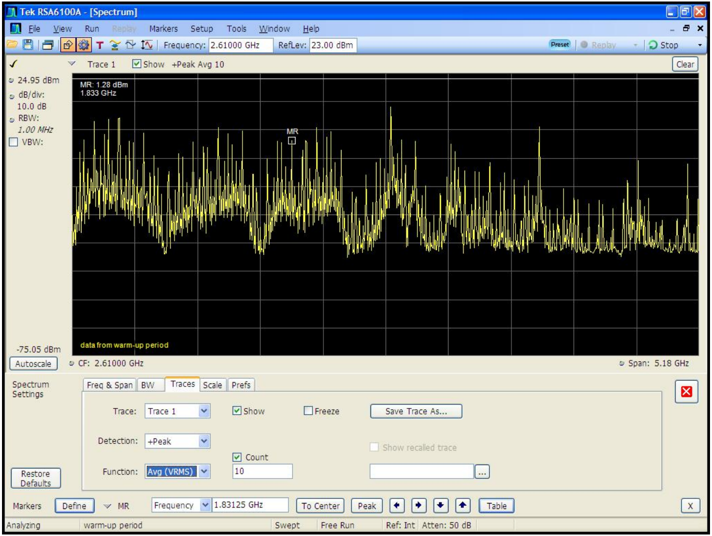


Longitudinal Feedback Kicker



STL3 Stripline



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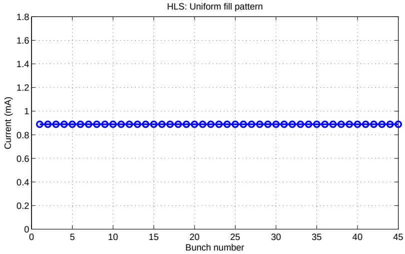
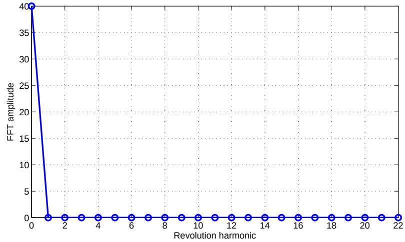
Fill Patterns and Coupled-bunch Instabilities





- Uneven fill patterns can reduce or increase growth rates;
- Theory by Shyam Prabhakar (SLAC-R-554);
- To damp mode 13, couple it to -13 (32);
- Fill pattern to maximize revolution harmonic 19 (32 – 13).

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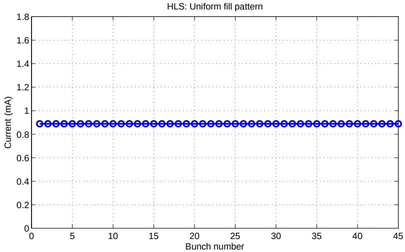

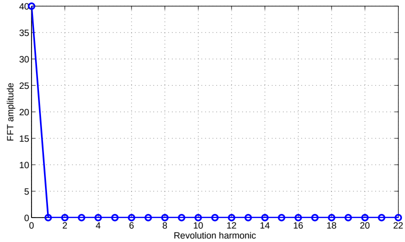

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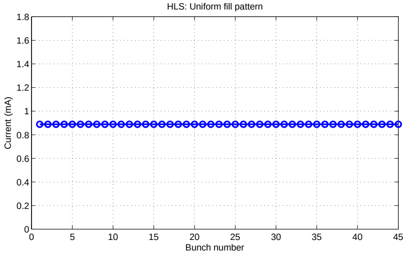

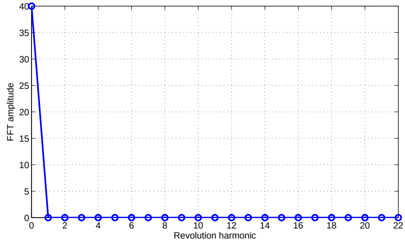

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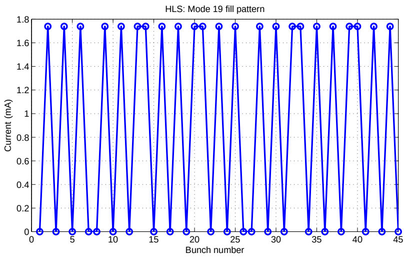

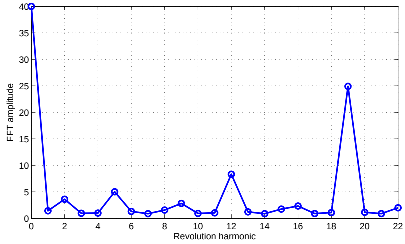

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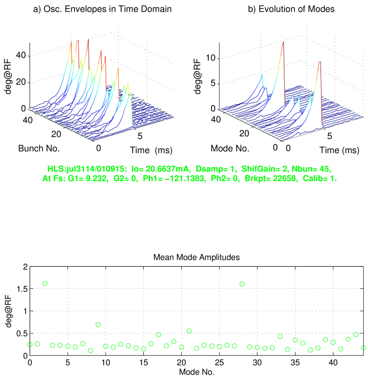
Observations in Rev19 Fill Pattern



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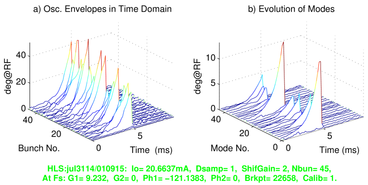

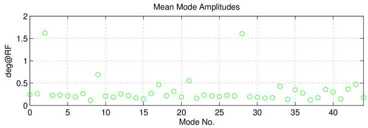

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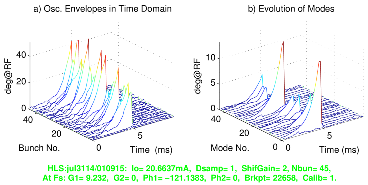

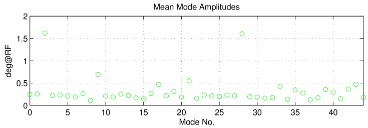

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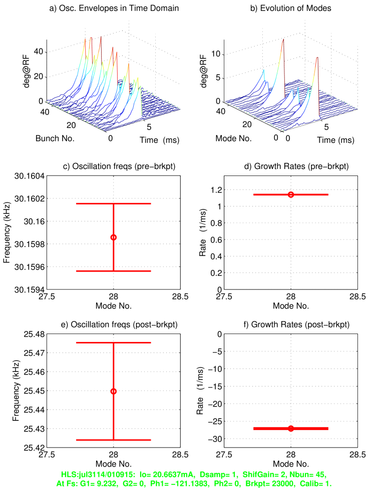

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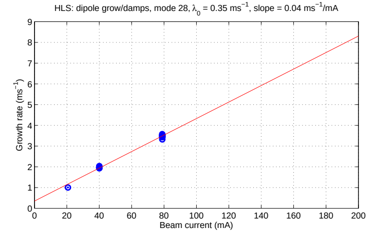
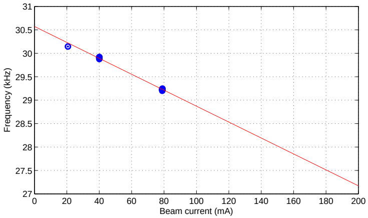
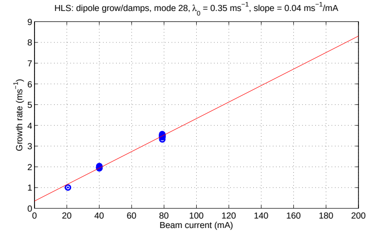
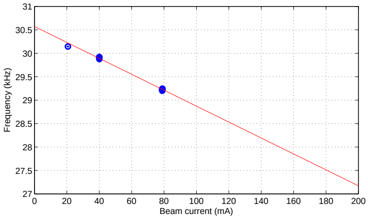




- Half the slope of mode 13 in even filling pattern;
- Still quite fast, limit around 160 mA;
- Fast growth rates — a lot of scatter;
- Somewhere between an even fill and this fill pattern is the ideal one.

Longitudinal Growth Rates vs. Beam Current





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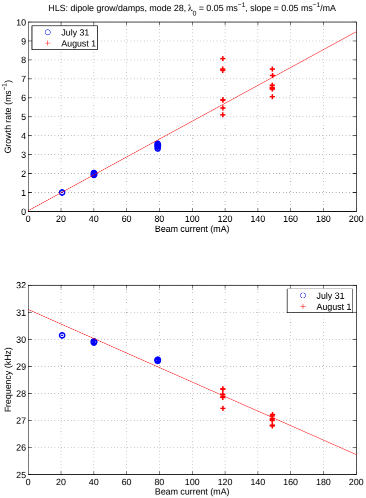

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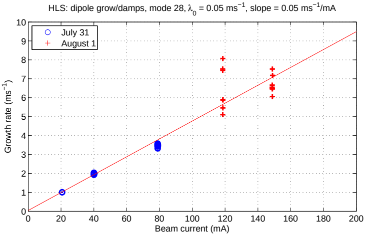

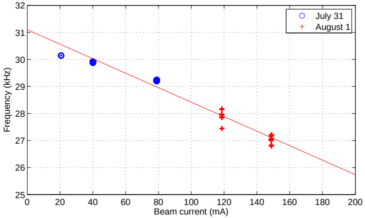

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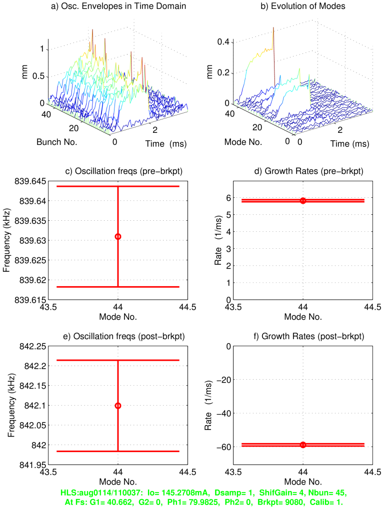
Vertical Grow/Damp Measurements



- Mode -1 is unstable;
- Likely both resistive wall and ions;
- Ion instabilities saturate quickly;
- Initial growth is reasonably exponential;
- 77 turns damping time!
- Need more measurements vs. beam current.

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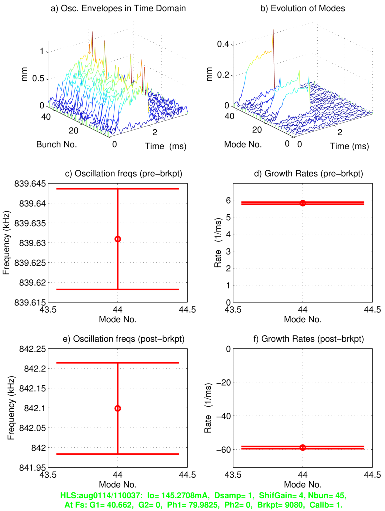

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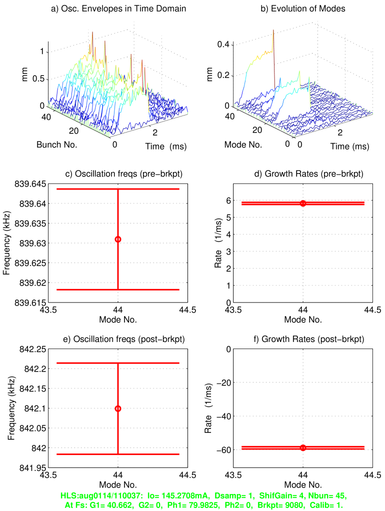

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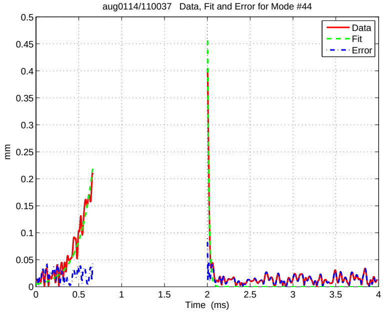

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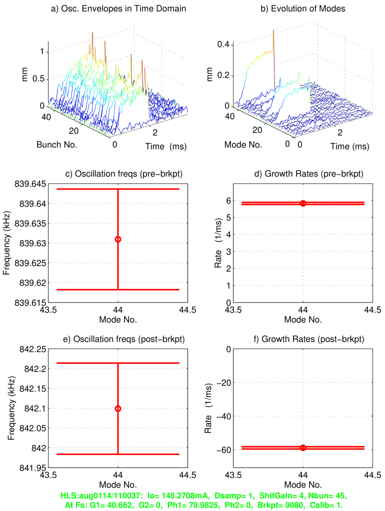

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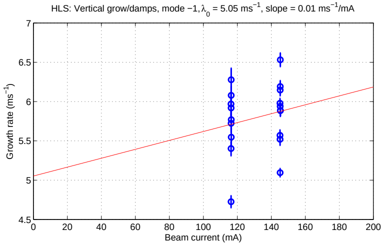

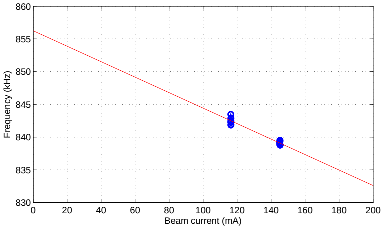

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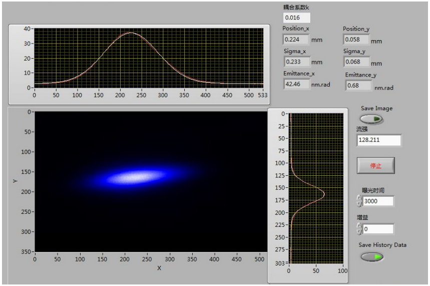
Lifetime and Feedback at 110 mA



- Feedback in all planes: 2.2 hours;
- Y off, X and Z on: 5.5 hours;
- Z off, X and Y on: 4.2 hours;
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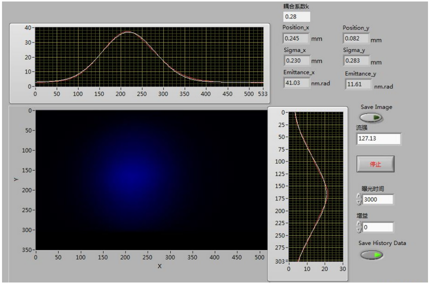

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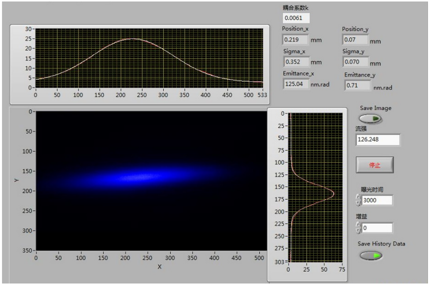

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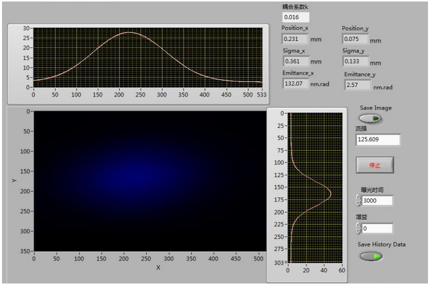

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