Bunch-by-bunch feedback commissioning at Indus-2

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December 16-20, 2013

Outline

1. Hardware Setup
   - System Installation
2. Feedback Operation and Beam Studies
   - Vertical Plane
   - Horizontal Plane
   - Longitudinal Plane
3. Bunch Cleaning

Work Summary

- Two baseband processors and the front/back-end are installed in the rack and connected to:
  - RF reference;
  - BPM hybrid outputs;
  - Power amplifiers.
- Set up vertical kicker with 4 striplines driven by two power amplifiers and two splitters;
- Set up horizontal kicker with 2 striplines (B, D), driven by two power amplifiers;
- Configured a prototype longitudinal kicker with an upconverter to RF frequency, 100 W amplifier driving one stripline.

Remaining Issues

- Fiducial signal has too much jitter and slow transitions, not stable within one RF bucket;
- Ran out of time while trying to set up longitudinal feedback;
- Need to work on Matlab interface for reading out diagnostic data for off-line analysis;
- Calibrations.

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- System Installation

2 Feedback Operation and Beam Studies
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- Horizontal Plane
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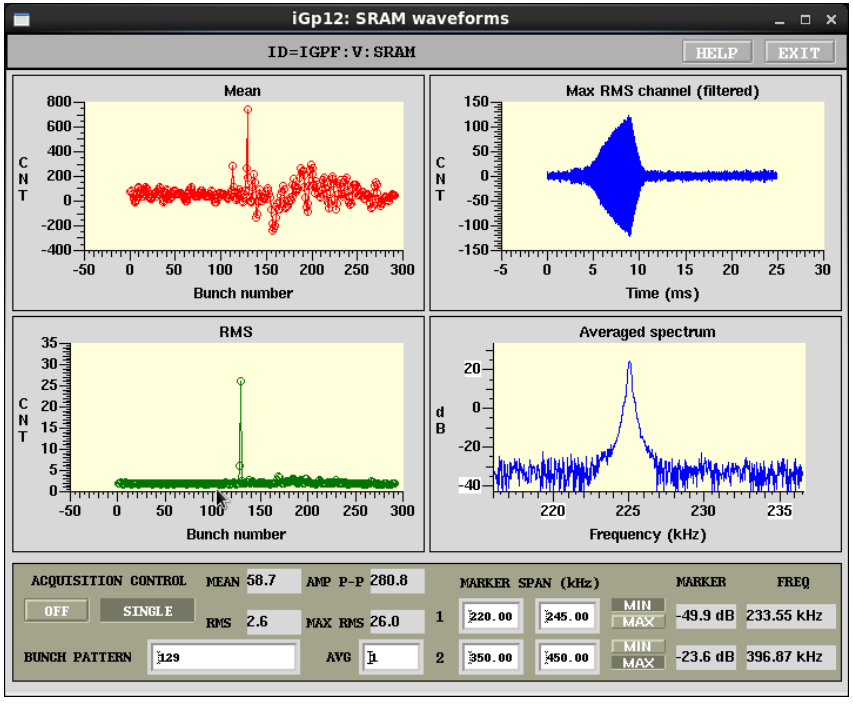
3 Bunch Cleaning

Single Bunch Measurements



- Started on Monday from configuring the vertical plane;
- By 14:45 closed the loop — drive/damp measurement;
- Beam transfer function — open loop;
- BTF — closed loop.

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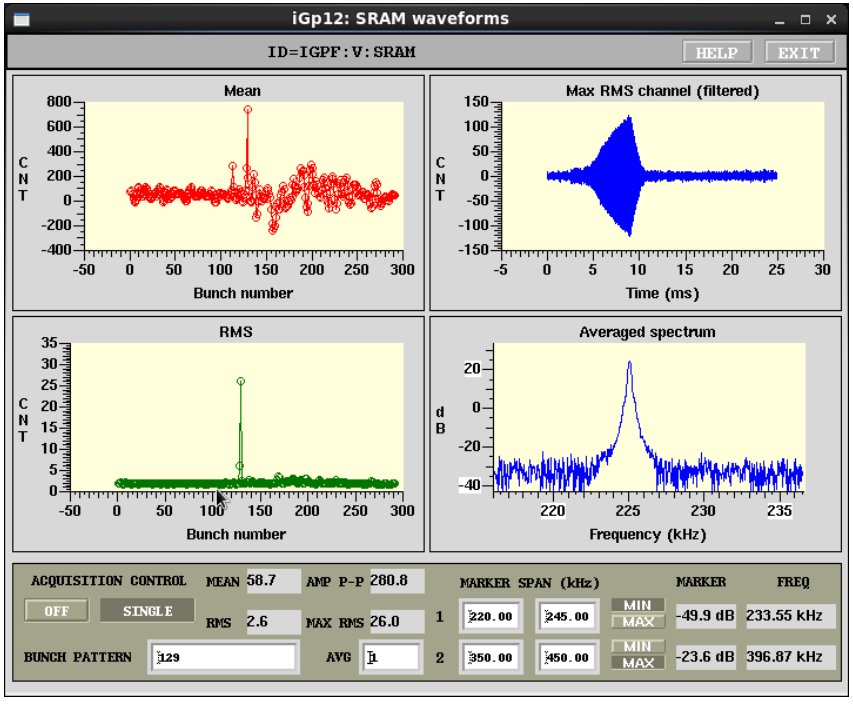

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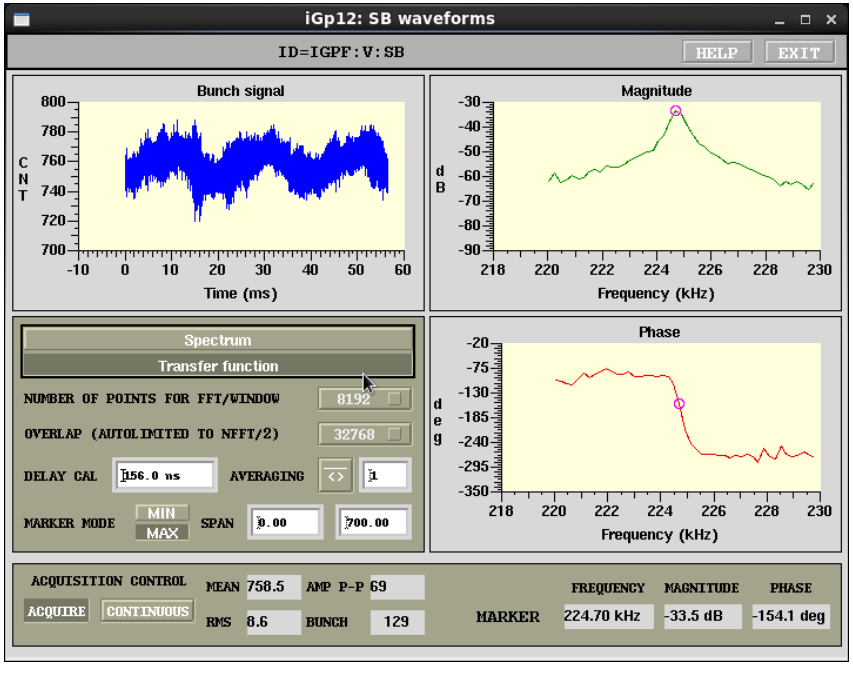

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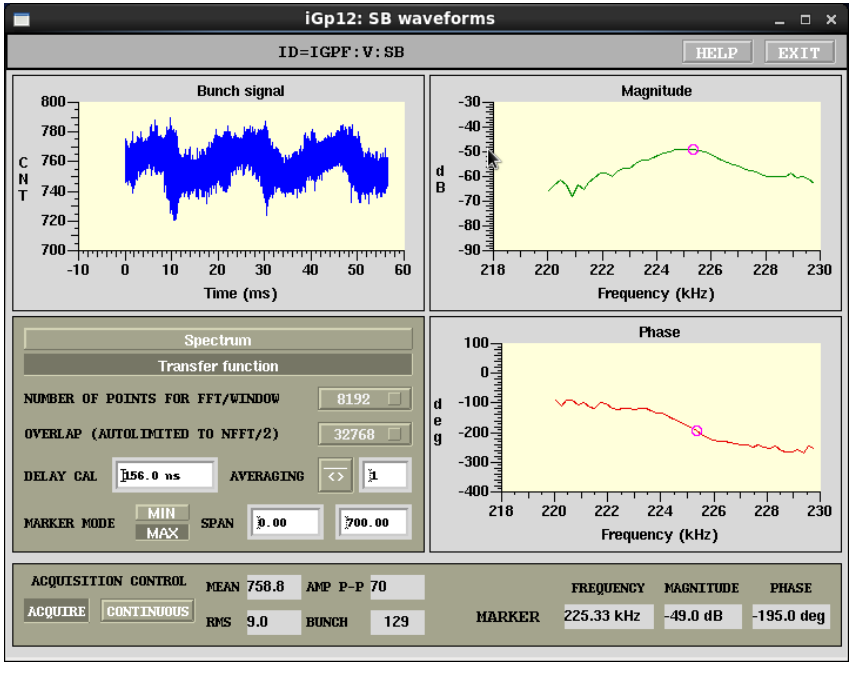

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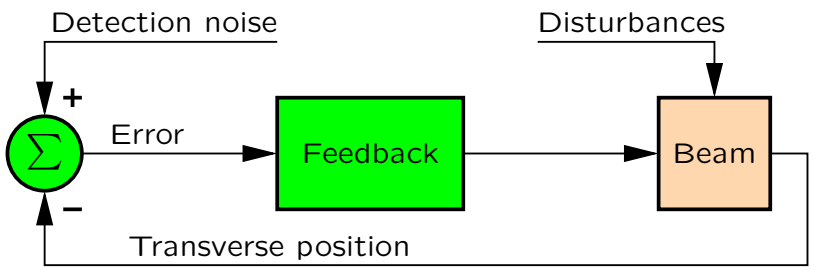

- Beam response is resonant at the tune frequency;
- Attenuation of detection noise by the feedback is proportional to the loop gain;
- Transfer gain from noise to the feedback input is $\frac{1}{1+L(\omega)}$
- Maximum attenuation at the resonance, thus a notch.

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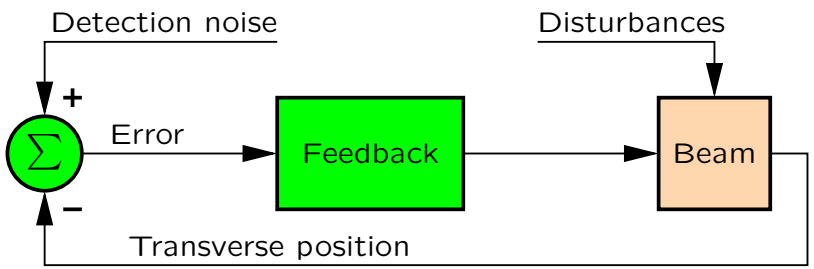

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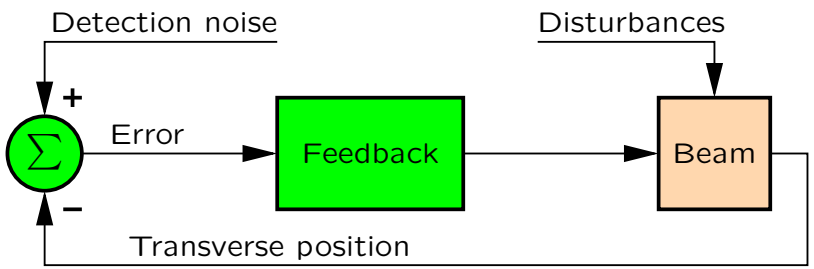

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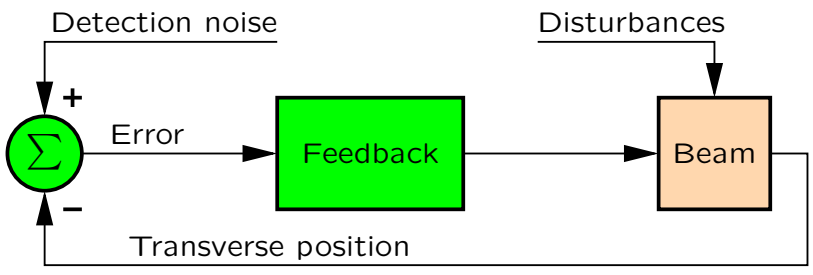

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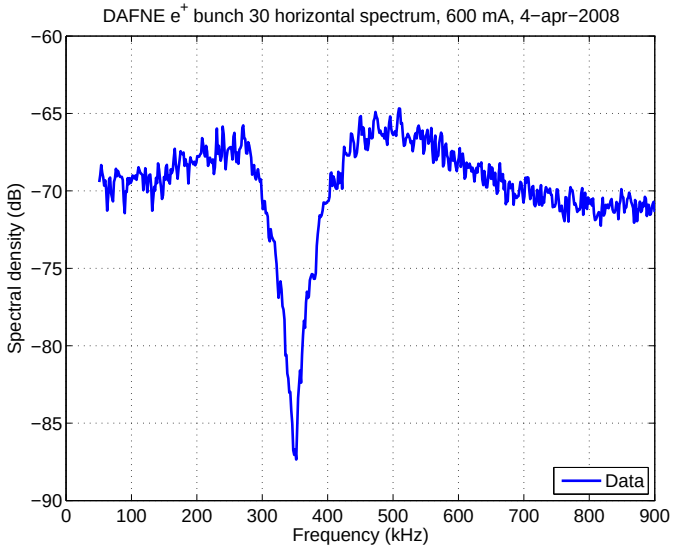

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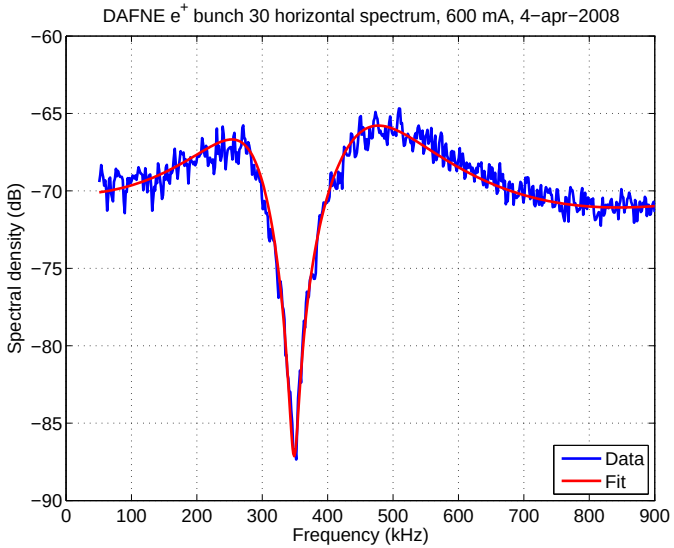

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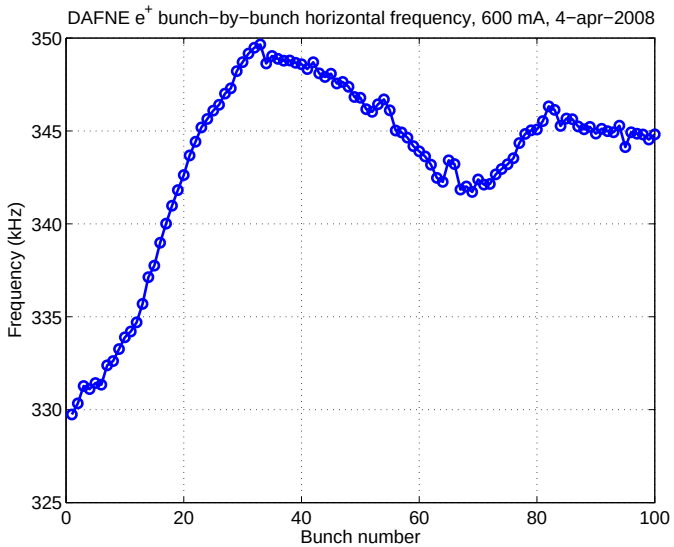

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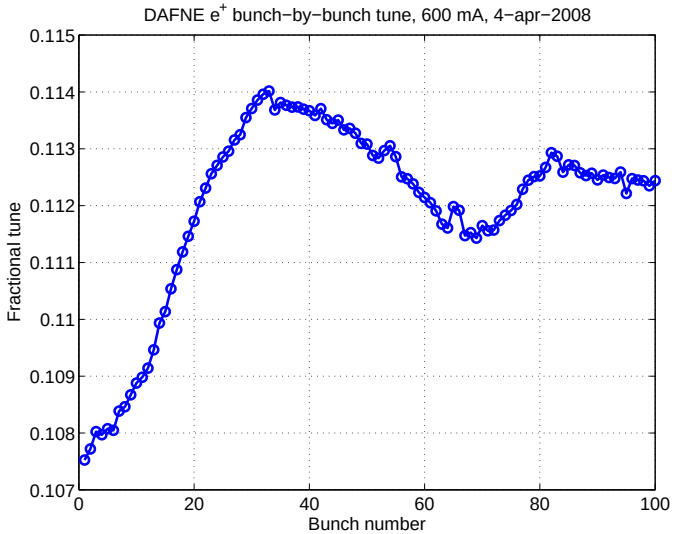

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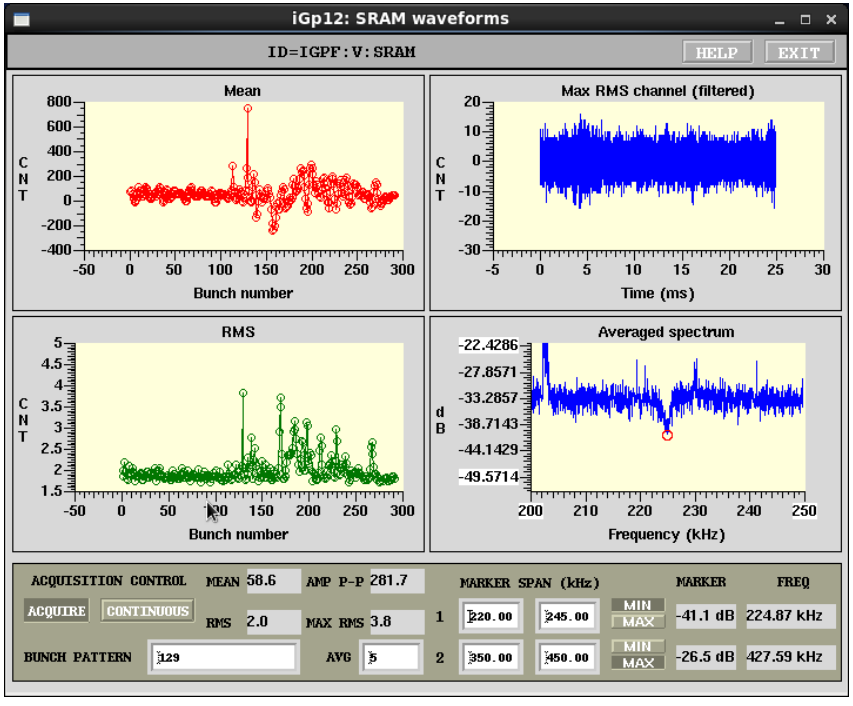

- Feedback loop closed at 550 MeV;
- Averaging 5 sweeps for bunch 129;
- See a clear notch;
- Minimum marker extracts the tune.

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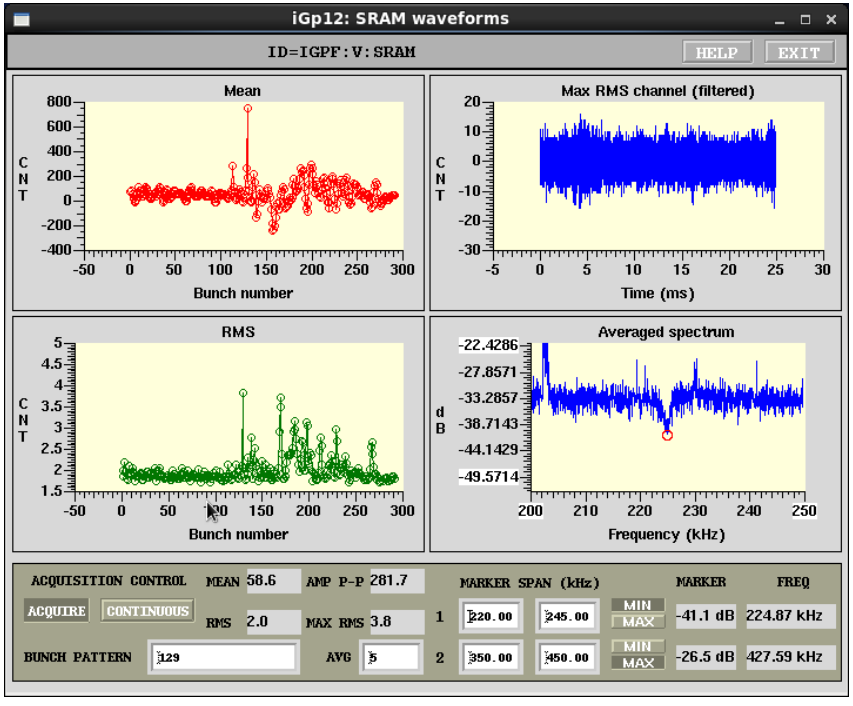

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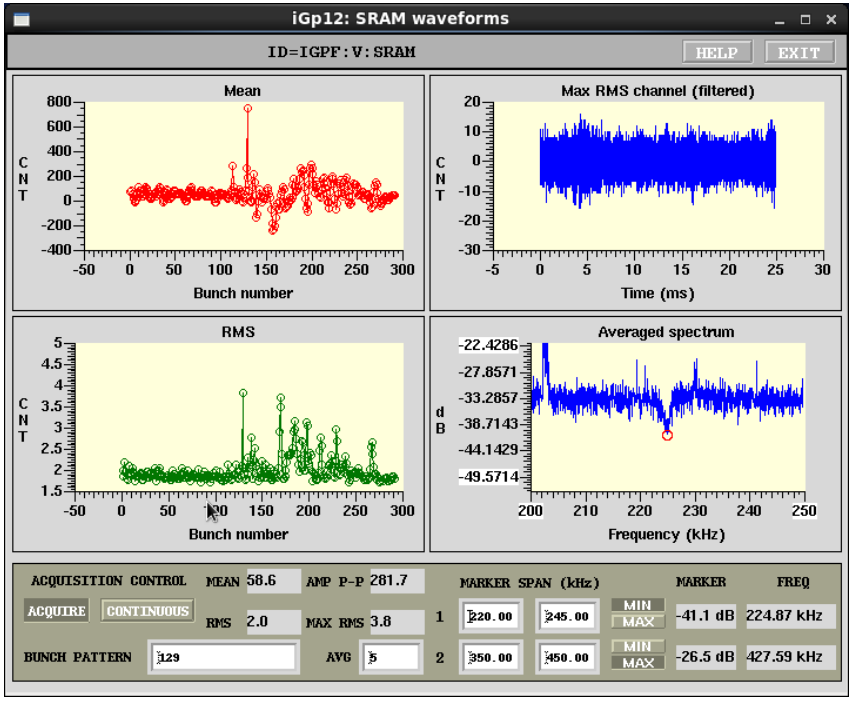

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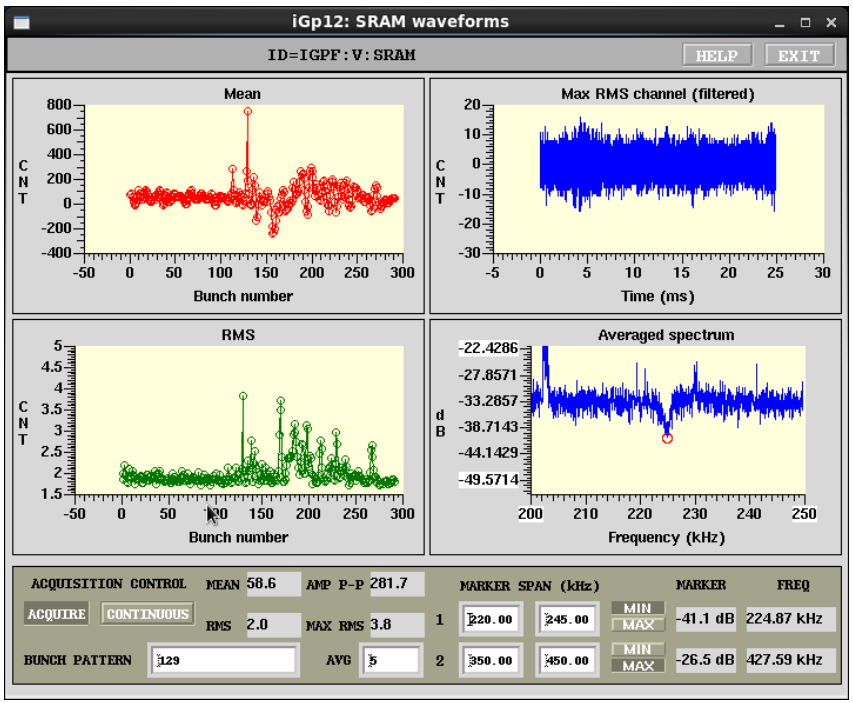

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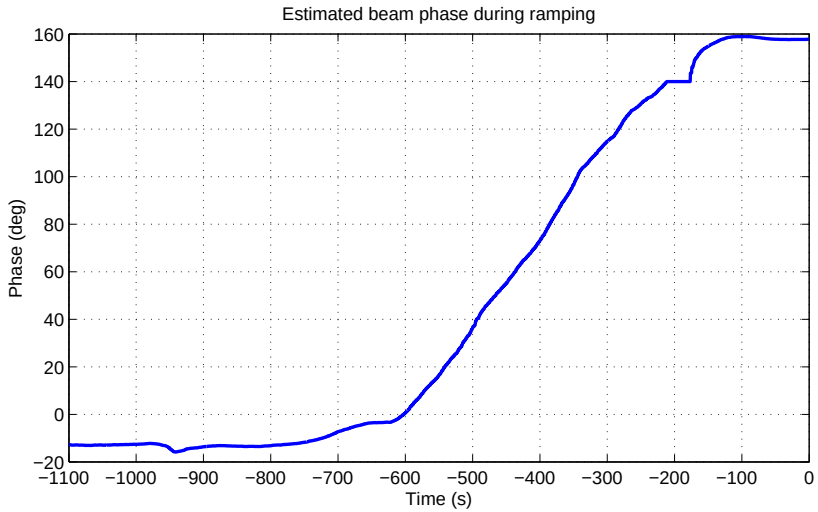

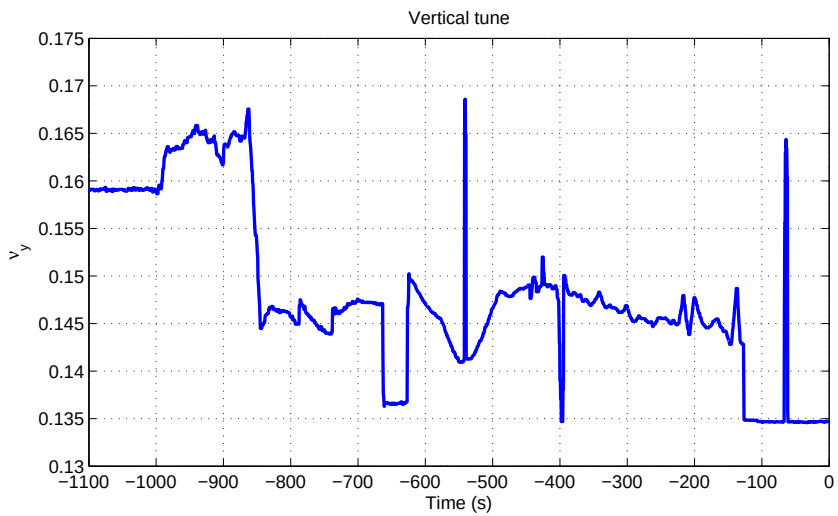

- Filled 180 bunches to 140 mA;
- Stable at 550 MeV;
- Second iGp12 connected to the longitudinal (sum) signal, serves as beam phase monitor;
- Successfully ramped to 2.5 GeV;
- See 4×10^{-4} tune variation (stored beam, 550 MeV).

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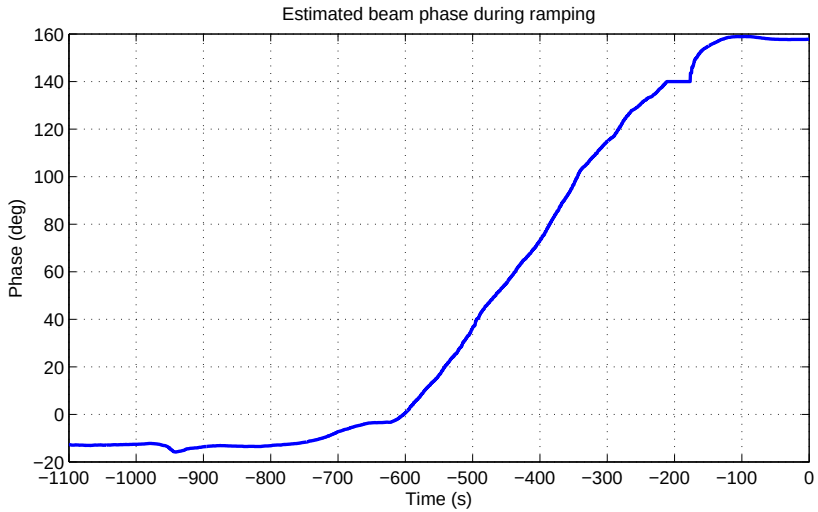

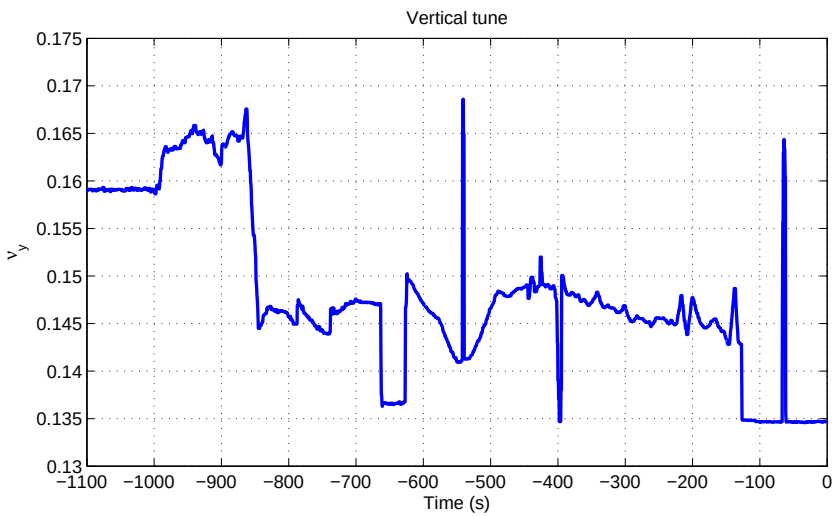

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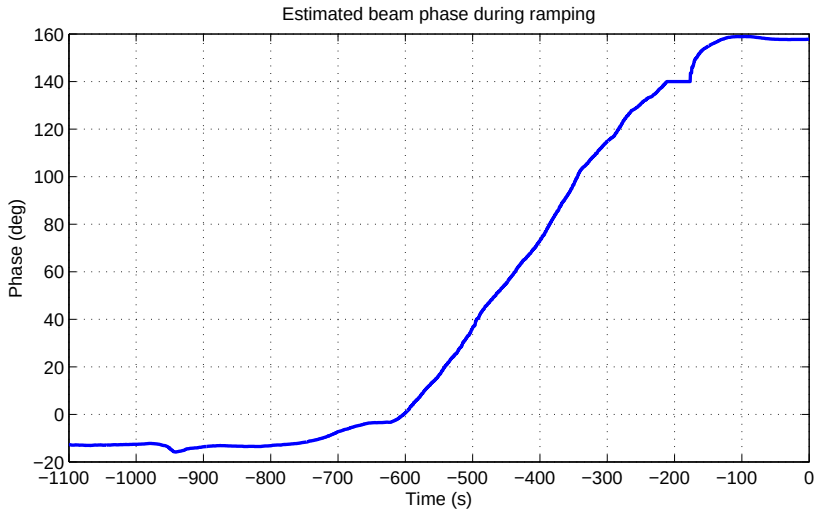

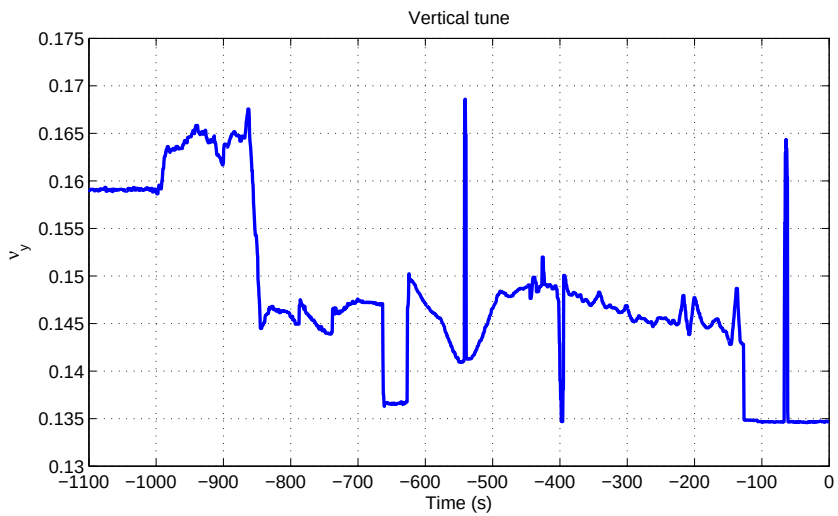

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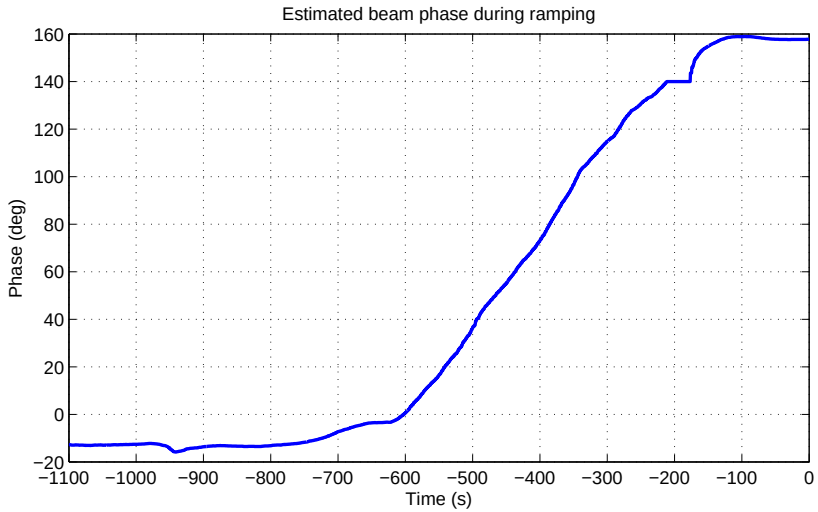

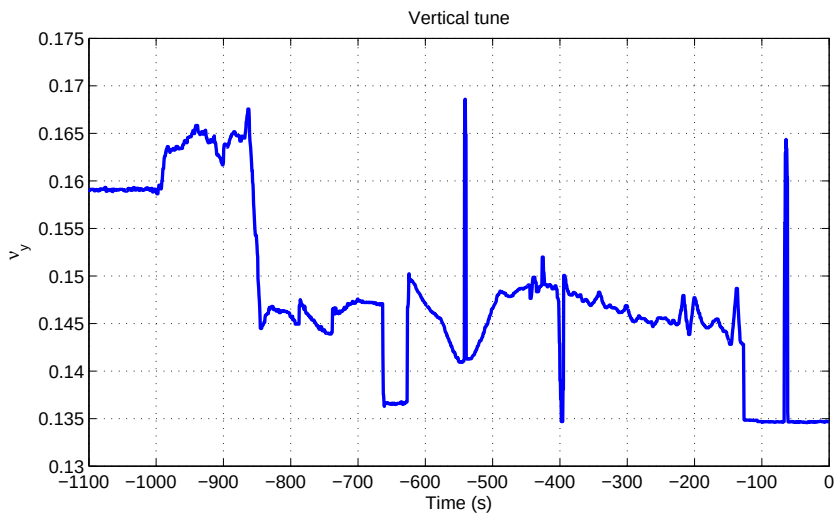

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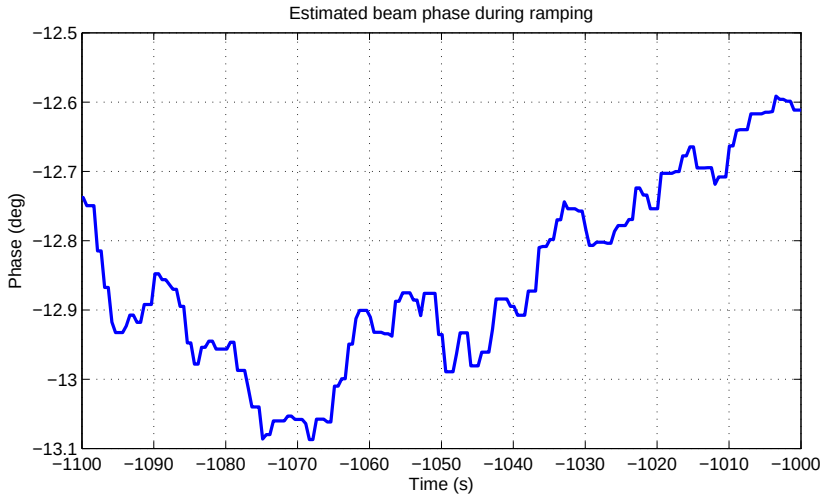

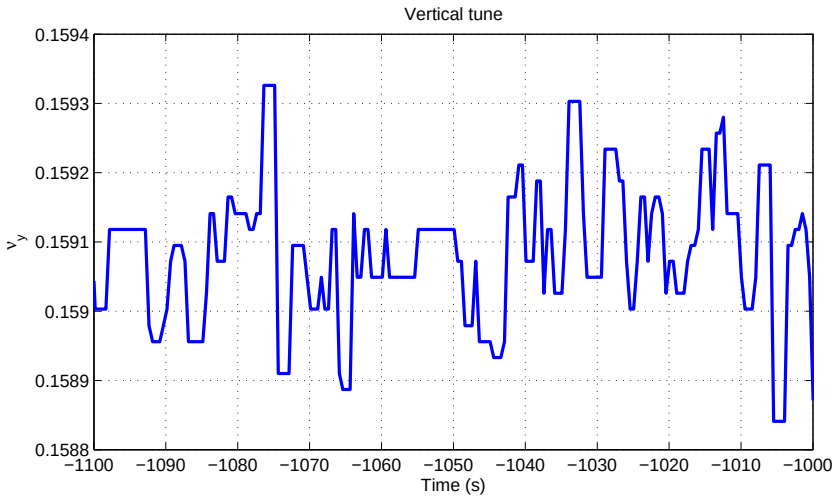

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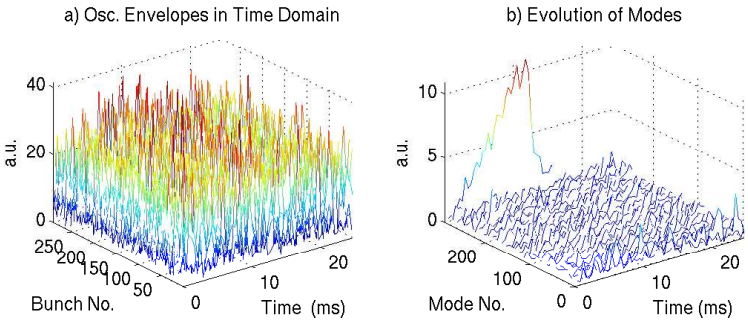
Vertical Grow/Damp: 20 mA @ 550 MeV



- With uniform filling the beam is bursting vertically at 20 mA;
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- Tune shift of 0.005 with amplitude;
- Behavior indicative of ion instabilities.

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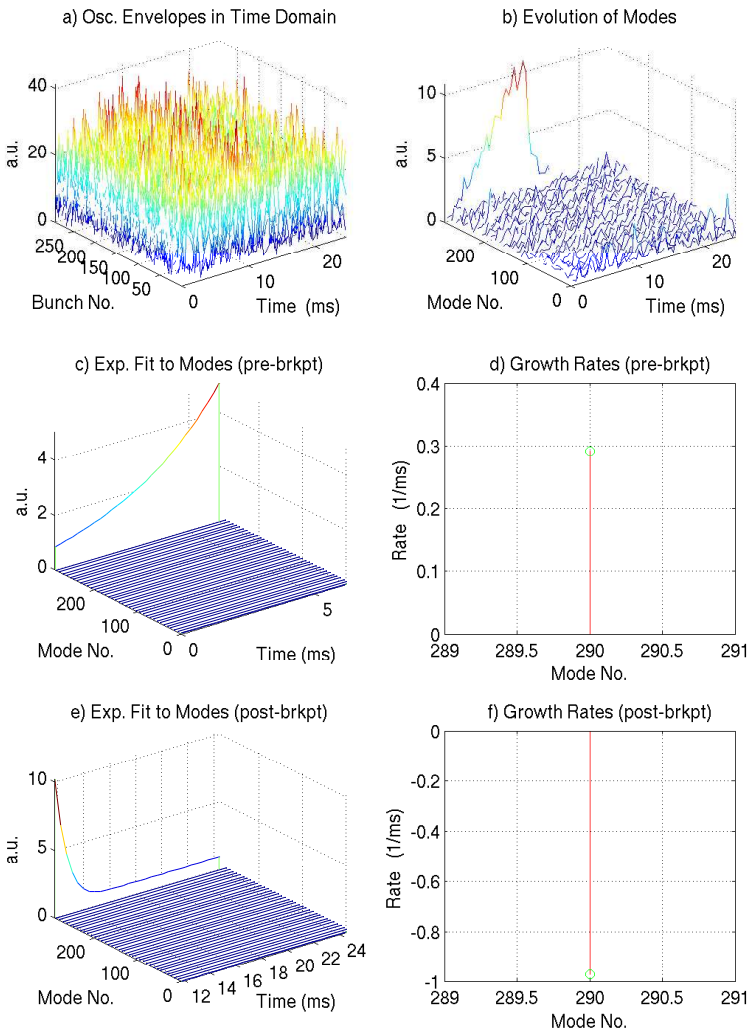

Indus−2:dec1813/122642: Io= 20mA, Dsamp= 1, ShifGain= 5, Nbun= 291,
At Fs: G1= 96.9526, G2= 0, Ph1= 105.7468, Ph2= 0, Brkpt= 20500, Calib= 1.

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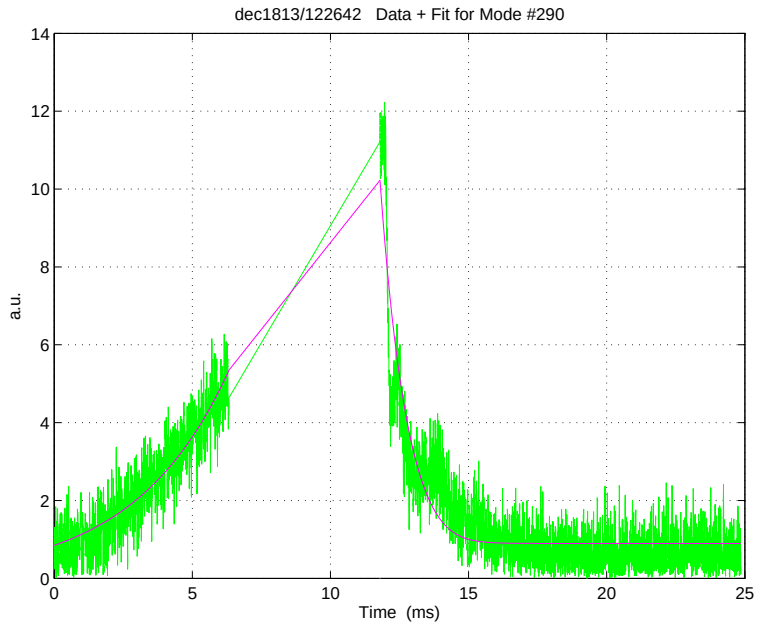

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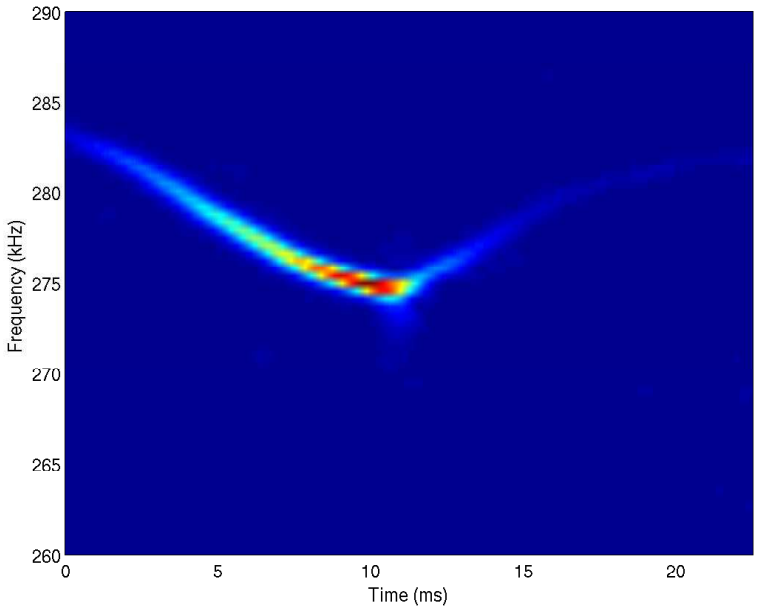

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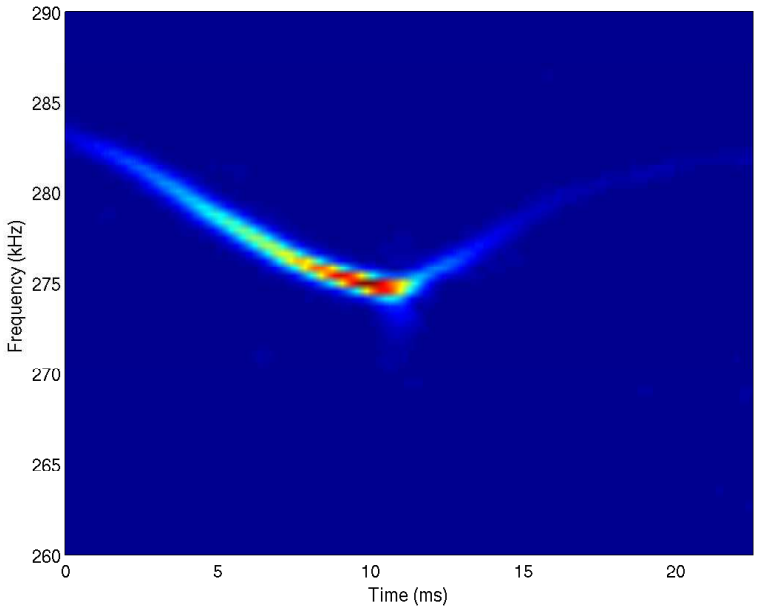

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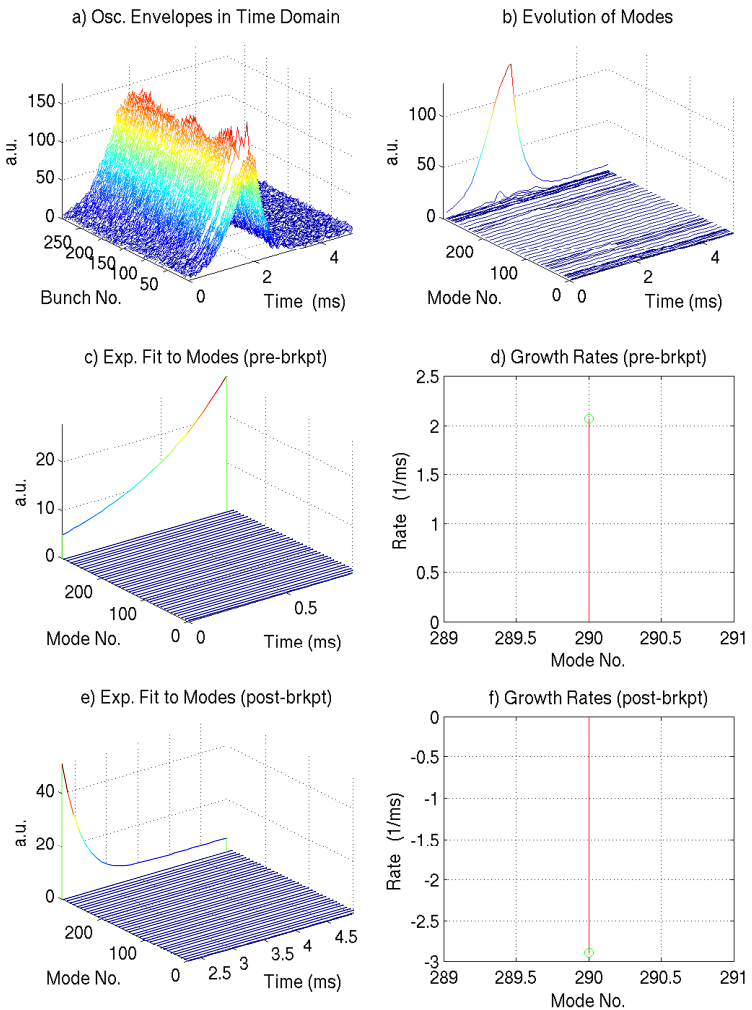

Indus−2:dec1913/203636: Io= 115mA, Dsamp= 1, ShifGain= 4, Nbun= 291,
At Fs: G1= 52.7181, G2= 0, Ph1= −81.2186, Ph2= 0, Brkpt= 4000, Calib= 1.

- At injection energy bursting not seen at 100–130 mA;
- After ramping — clear instability with a similar signature;
- Reasonable damping;
- Tune transient goes in the opposite direction?

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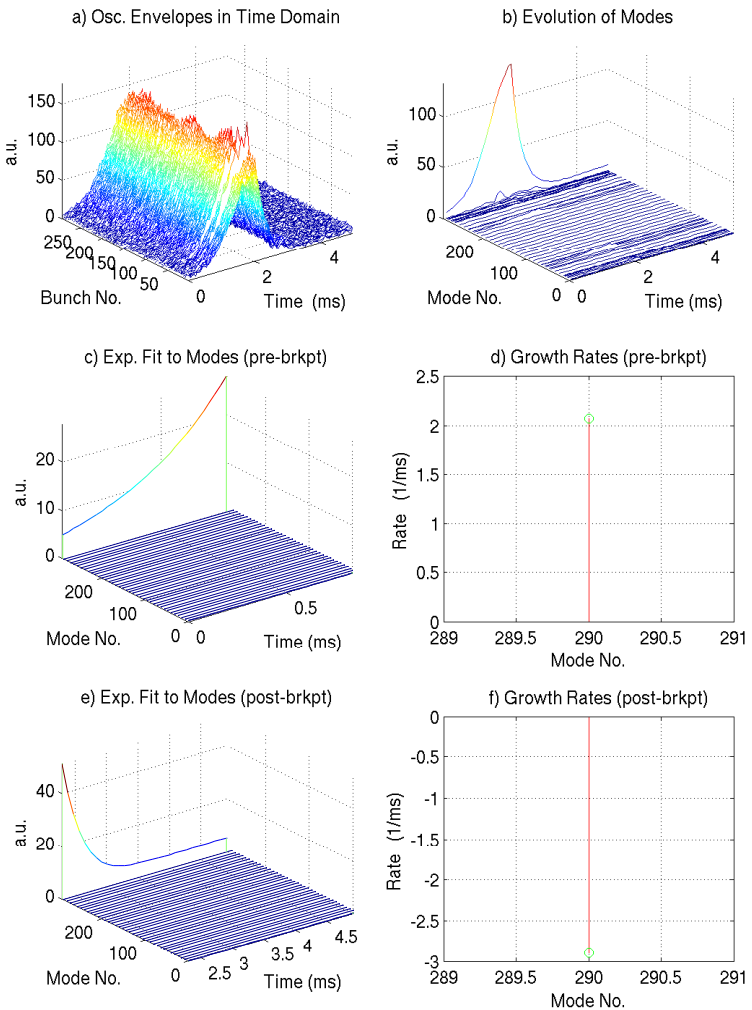

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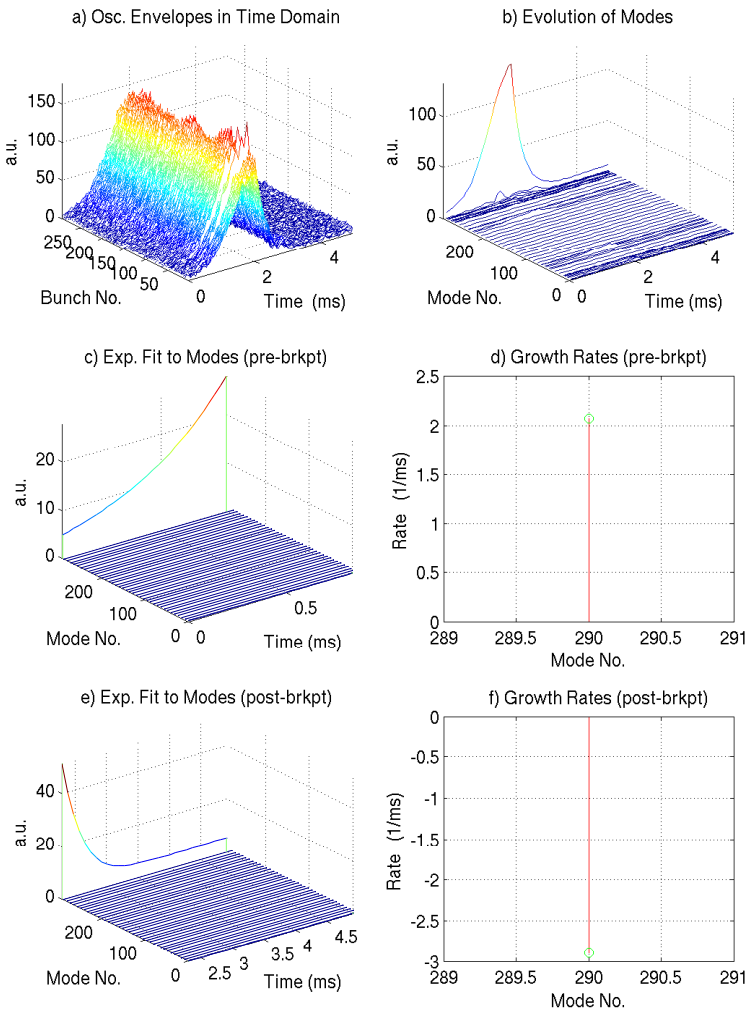

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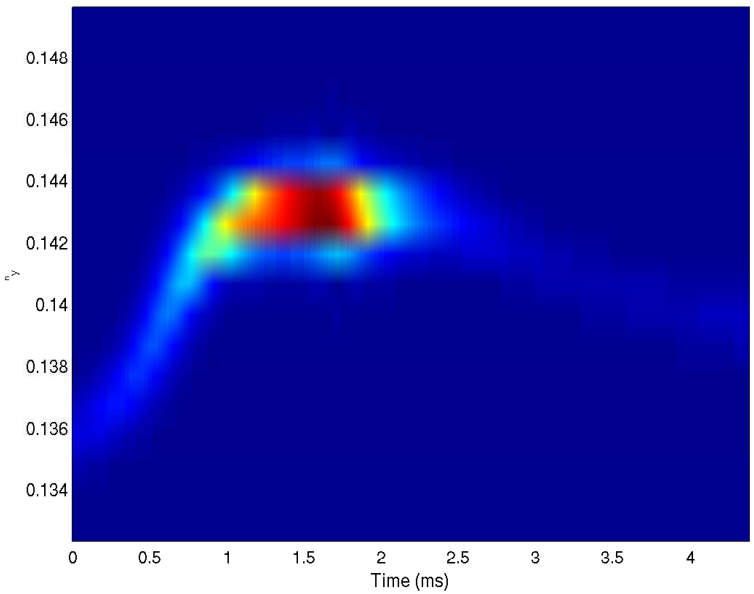

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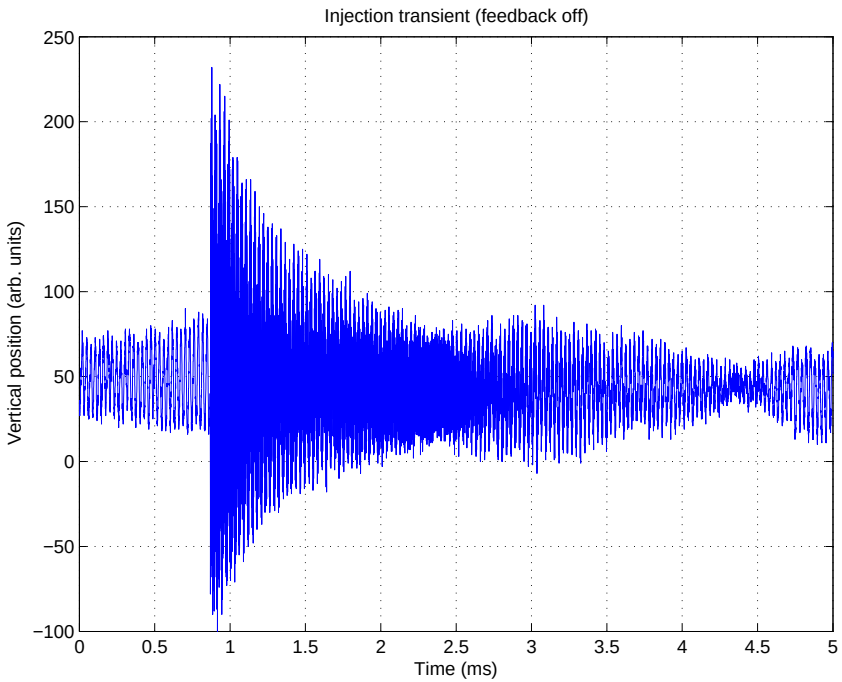
Injection Transient



- Injection transient captured using external trigger;
- Vertical plane — coupling from horizontal;
- Feedback damps the oscillation very quickly.

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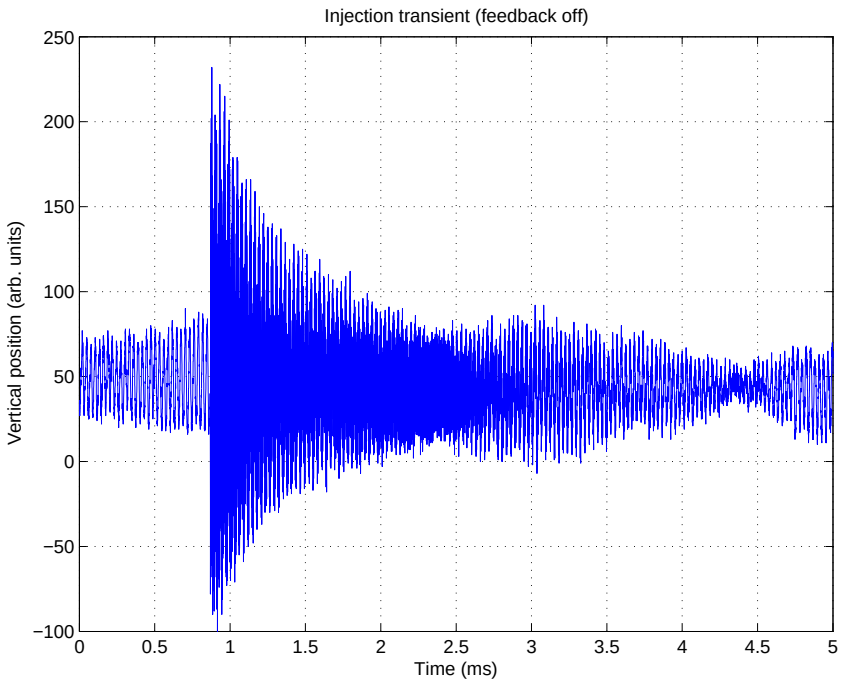

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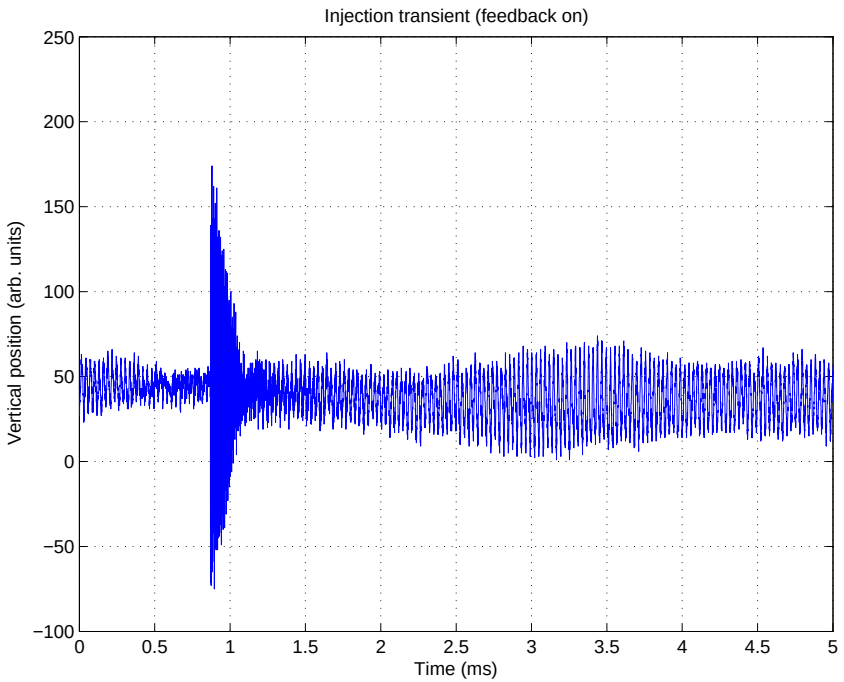

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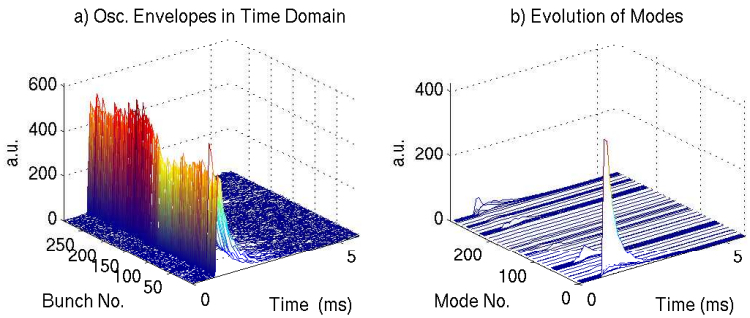
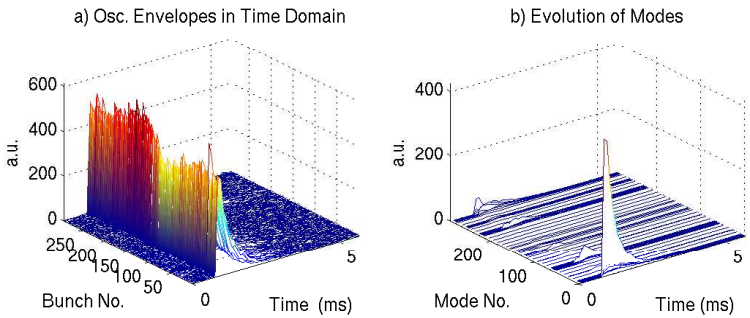


Indus−2:dec1913/190443: Io= 65mA, Dsamp= 1, ShifGain= 5, Nbun= 291,
At Fs: G1= 95.861, G2= 0, Ph1= −77.13, Ph2= 0, Brkpt= 43202, Calib= 1.

- Modal analysis shows mode 0 — all bunches moving in phase;
- Stored beam perturbation due to imperfect injection kicker bump closure;
- Feedback dramatically speeds up the damping;
- See improvement in injection rate with feedback, expect a bigger effect from the horizontal one.

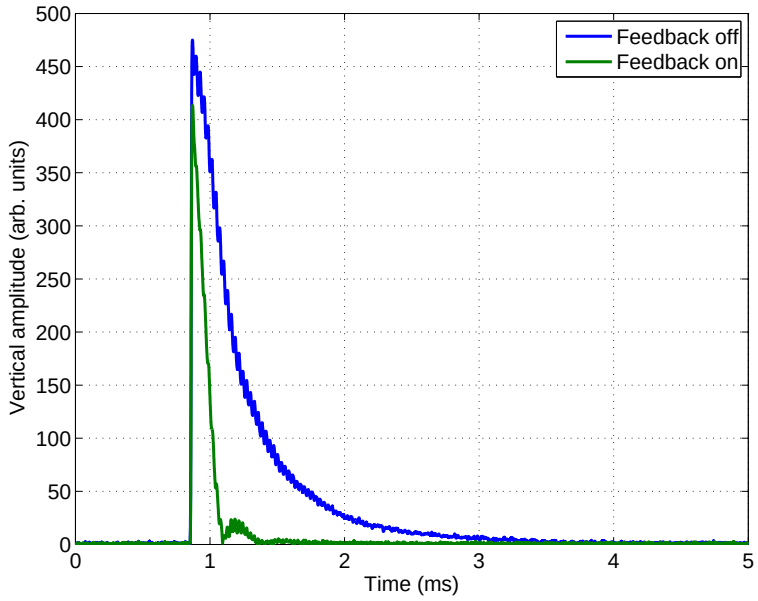
Injection Transient (Continued)



Indus−2:dec1913/190443: Io= 65mA, Dsamp= 1, ShifGain= 5, Nbun= 291,
At Fs: G1= 95.861, G2= 0, Ph1= −77.13, Ph2= 0, Brkpt= 43202, Calib= 1.

- Modal analysis shows mode 0 — all bunches moving in phase;
- Stored beam perturbation due to imperfect injection kicker bump closure;
- Feedback dramatically speeds up the damping;
- See improvement in injection rate with feedback, expect a bigger effect from the horizontal one.

Injection Transient (Continued)



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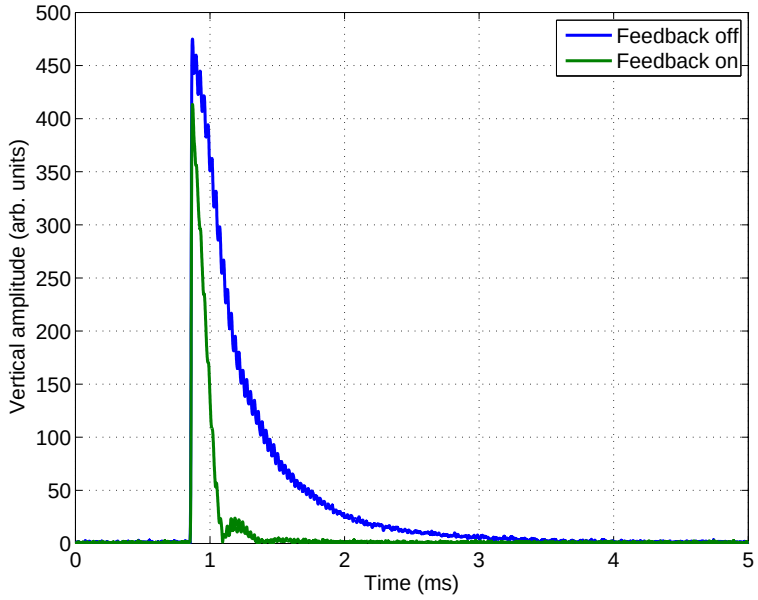

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1. Hardware Setup
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2. Feedback Operation and Beam Studies
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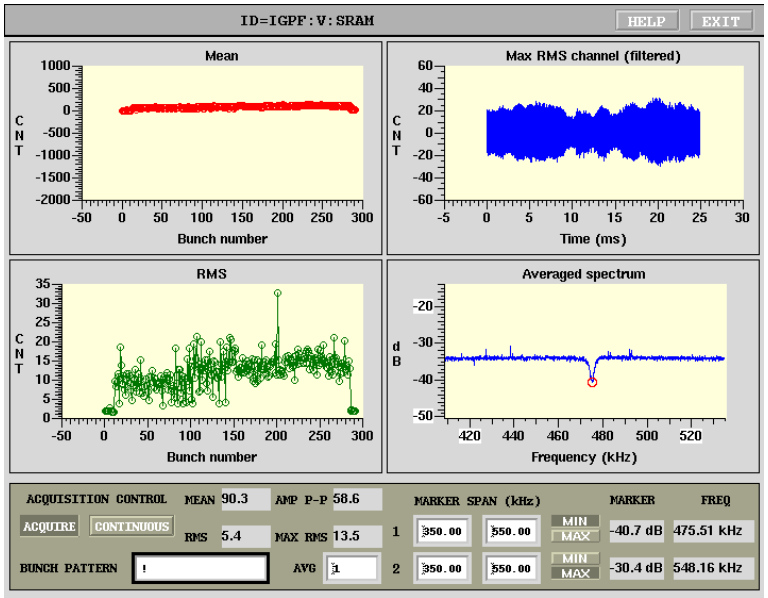
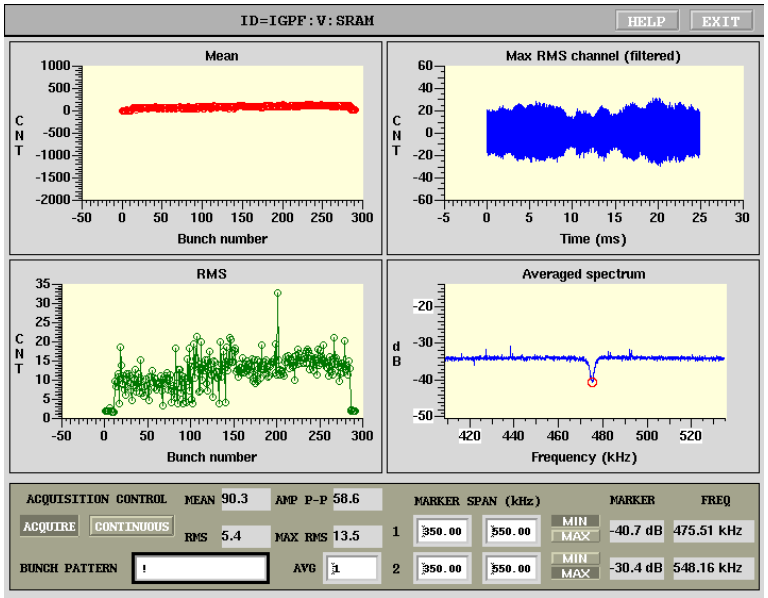
   - Horizontal Plane
   - Longitudinal Plane
3. Bunch Cleaning

Tuning And Feedback Notch



- On Wednesday had 20 mA in 291 bunches for a while;
- Used bunch cleaning (vertical) to carve out an isolated bunch;
- Tuned horizontal feedback — nice notch.

Tuning And Feedback Notch



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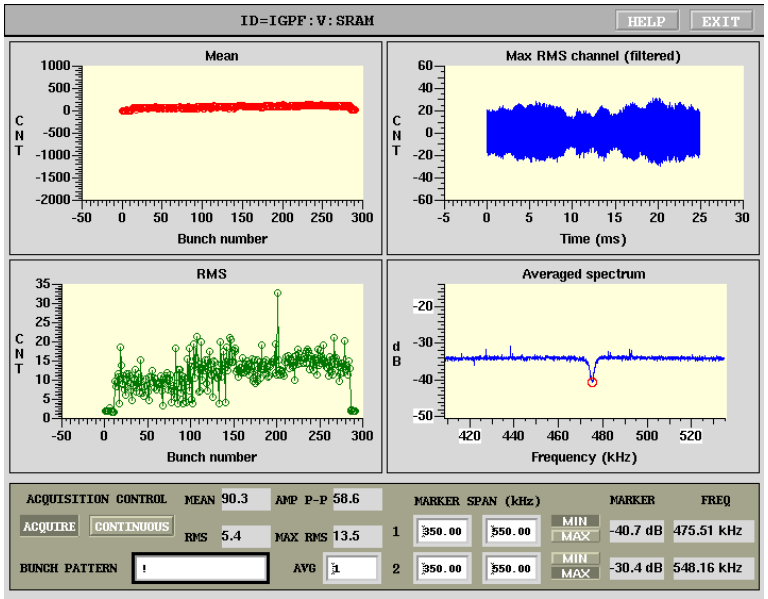

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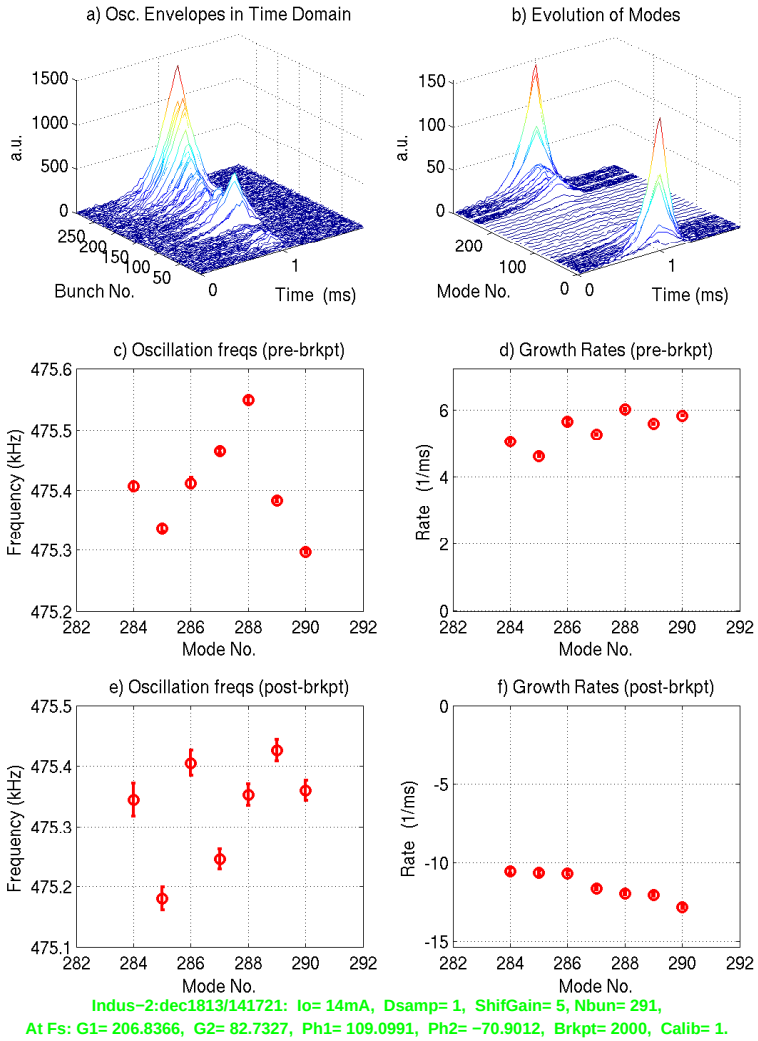
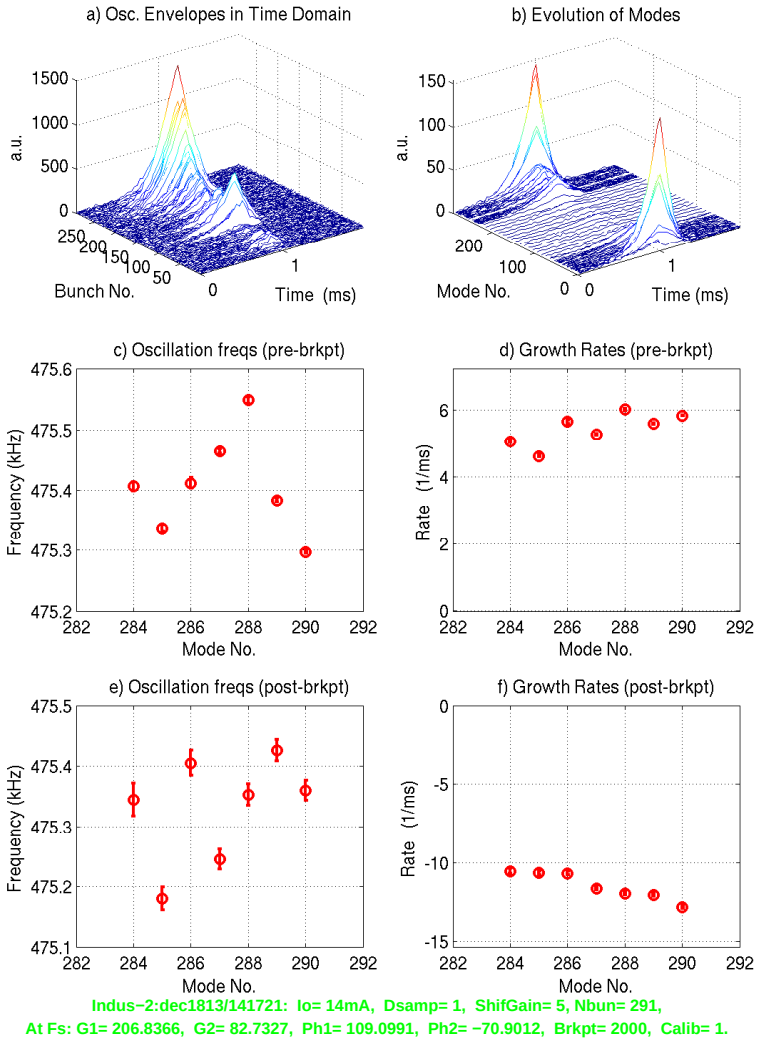


Indus−2:dec1813/141721: Io= 14mA, Dsamp= 1, ShifGain= 5, Nbun= 291,
At Fs: G1= 206.8366, G2= 82.7327, Ph1= 109.0991, Ph2= −70.9012, Brkpt= 2000, Calib= 1.

- Stable beam — use positive feedback;
- Many modes are excited, not an indication of actual instabilities;
- Extract open and closed loop eigenvalues.

Drive/Damp Measurement



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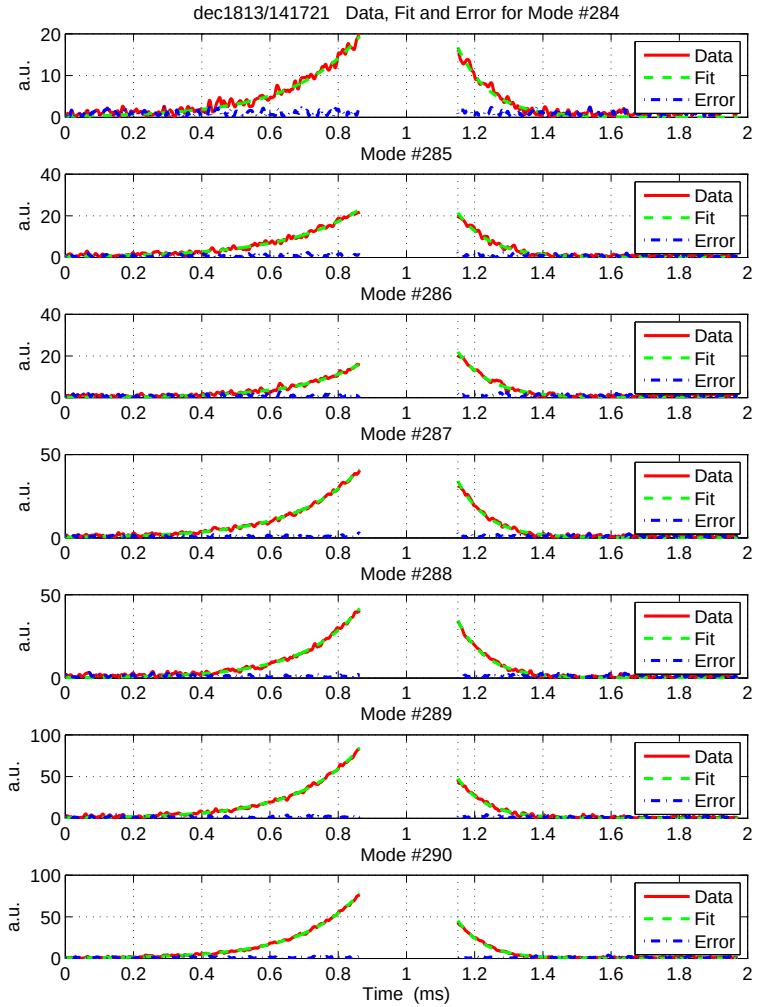

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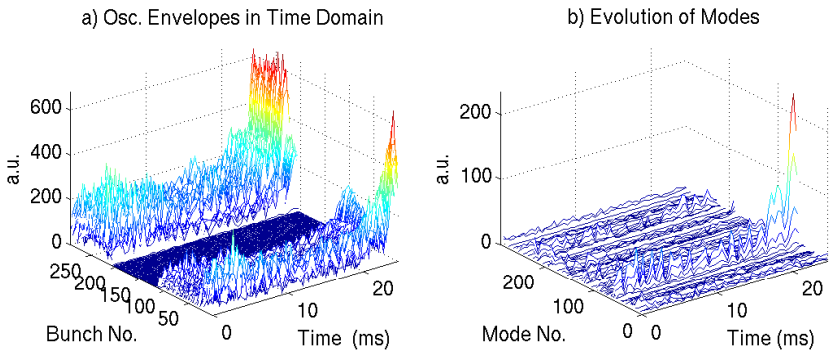
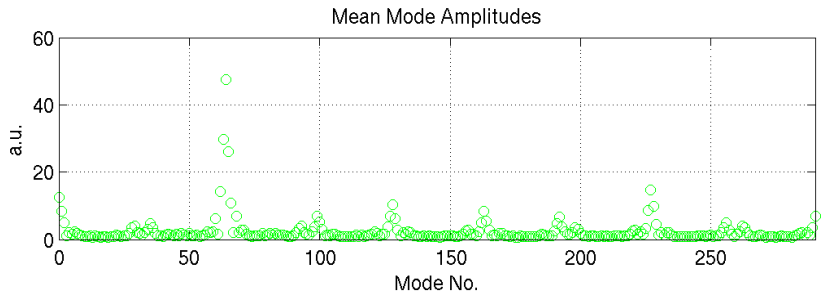
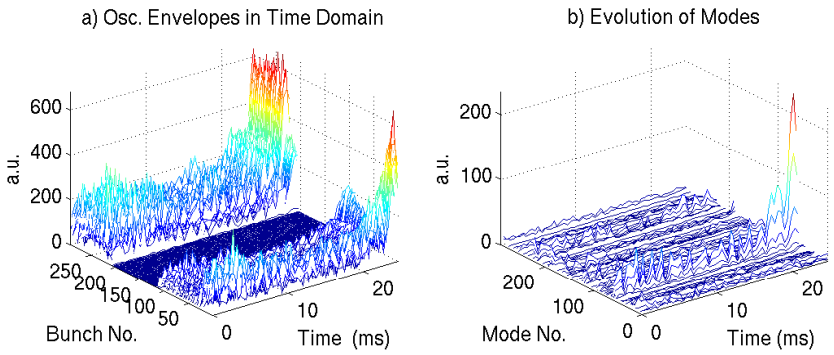
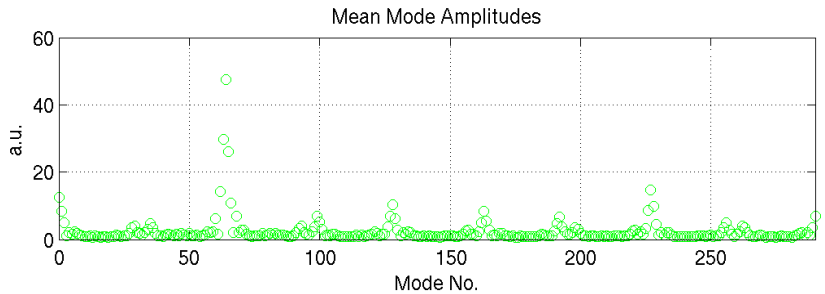




- Only open loop data so far;
- At 76 mA, dominated by mode 64;
- Very similar spectrum at 137 ma;
- Uniform fill at 113 mA, see mode 64;
- At 2.5 GeV, 95 mA only see driven motion (mode 0).

Modal Measurements





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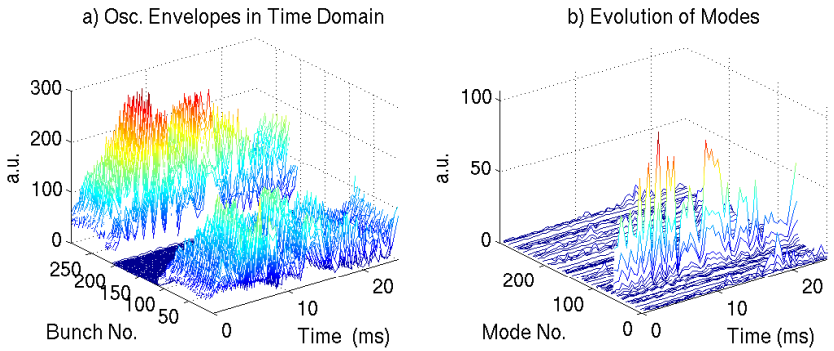
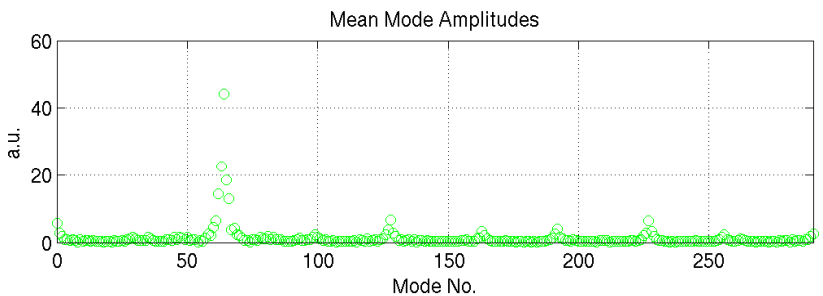


Indus−2:dec1713/190500: Io= 137mA, Dsamp= 1, ShifGain= 0, Nbun= 291,
At Fs: G1= 1.5347, G2= 0, Ph1= −25.2, Ph2= 0, Brkpt= 43202, Calib= 1.



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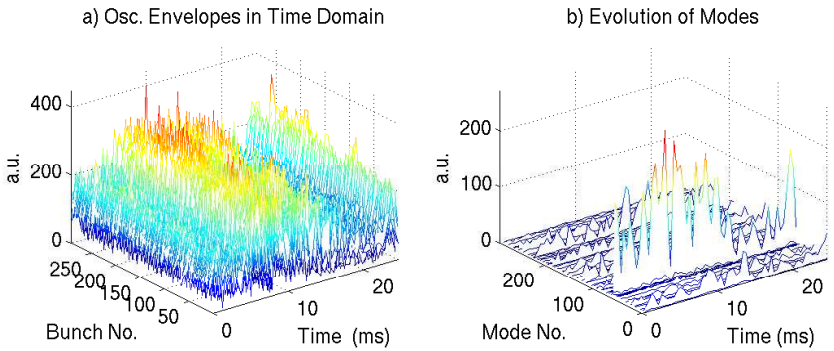
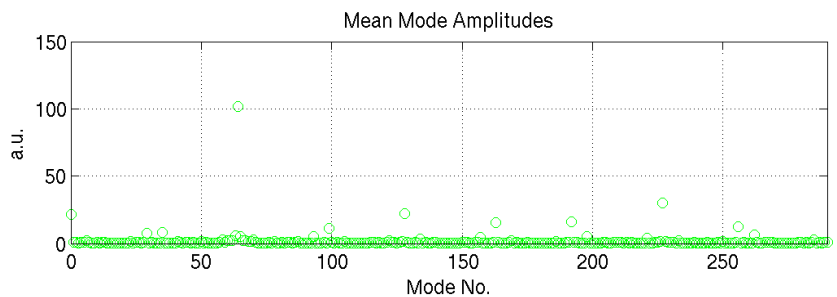


Indus−2:dec1913/195154: Io= 113mA, Dsamp= 1, ShifGain= 2, Nbun= 291,
At Fs: G1= 29.0344, G2= 29.0344, Ph1= 26.1609, Ph2= −153.8391, Brkpt= 43202, Calib= 1.



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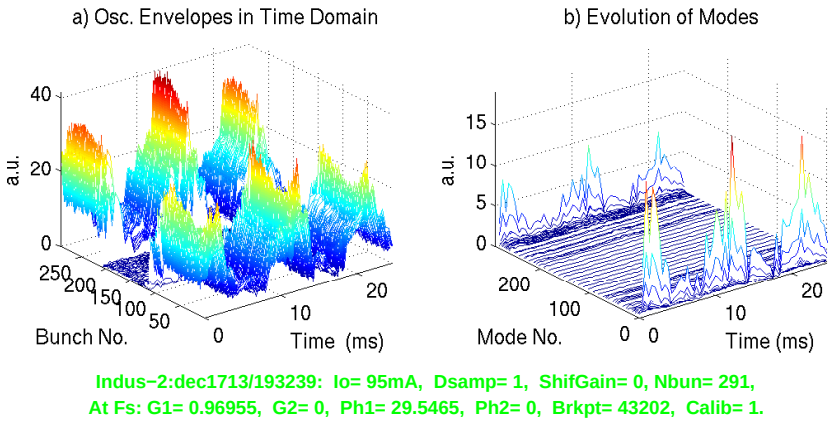

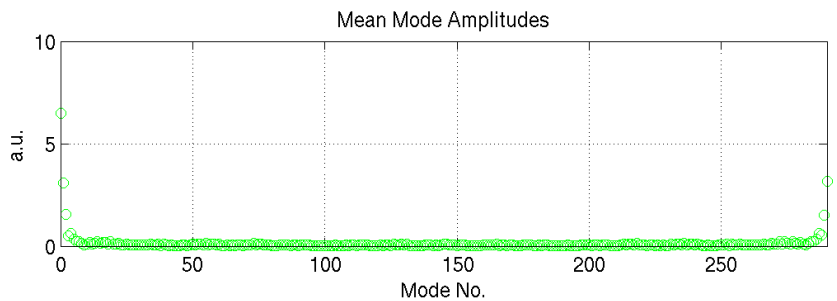

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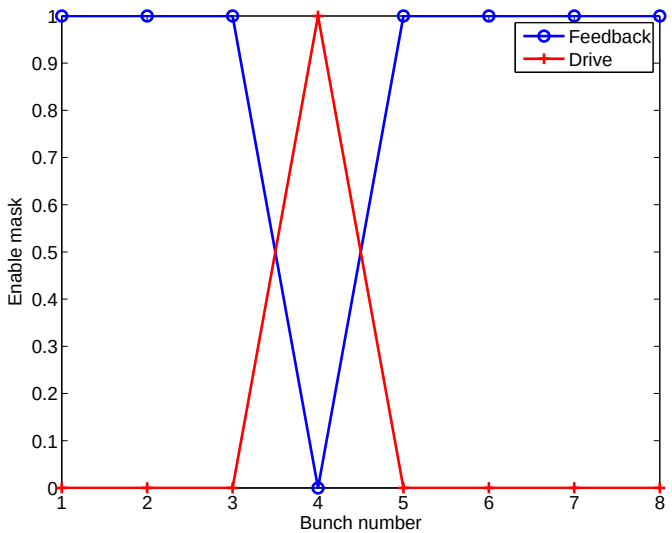

- Use bunch enable masks to define cleaning pattern;
- Enable feedback for all bunches we want to keep;
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- Drive mask is the complement of the feedback mask;
- Use swept sine excitation to drive selected bunches to large transverse amplitudes.

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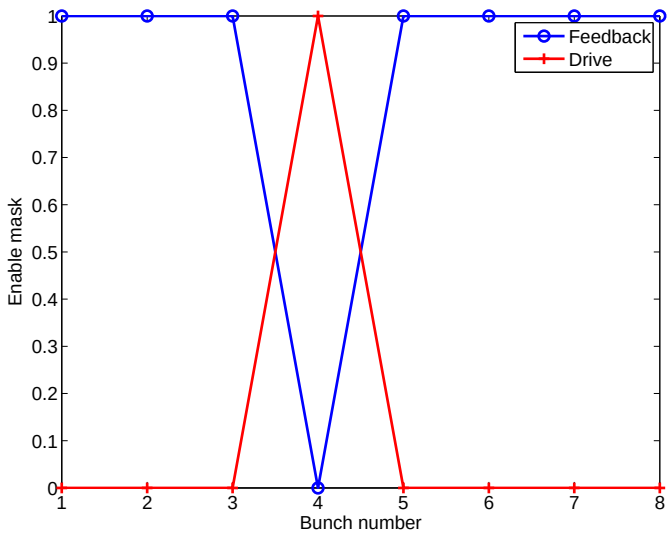

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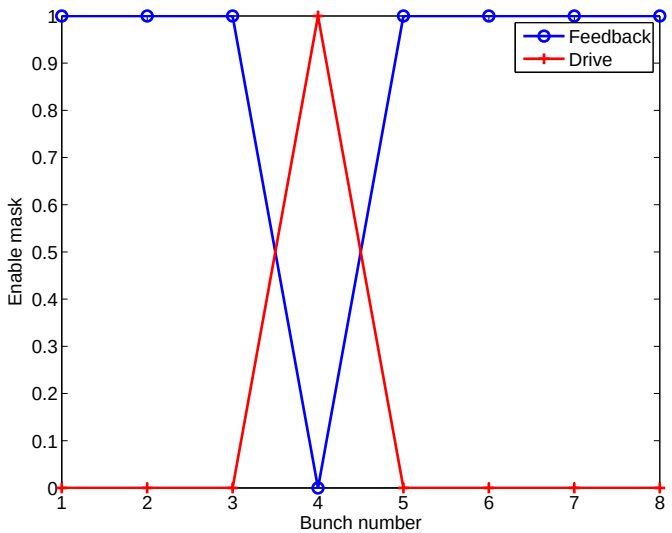

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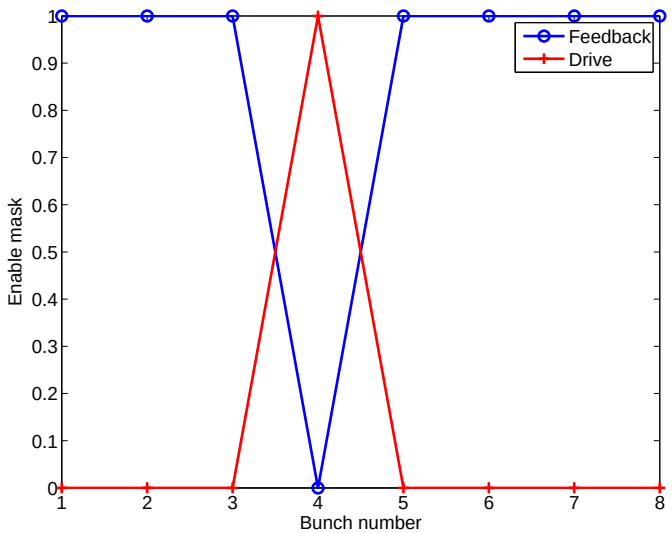

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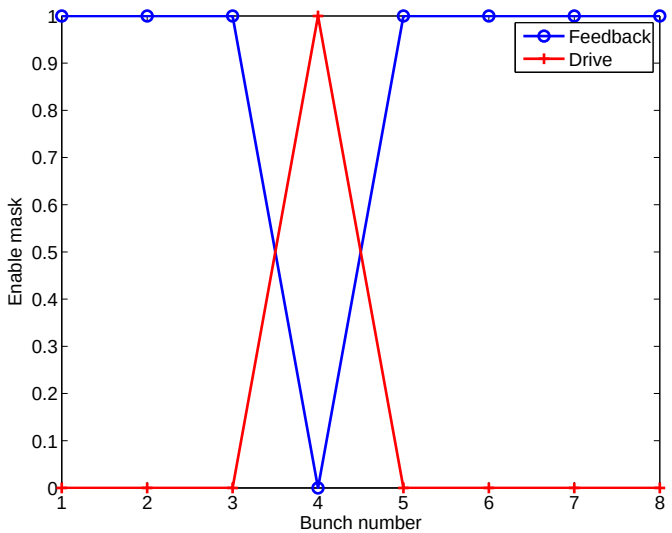

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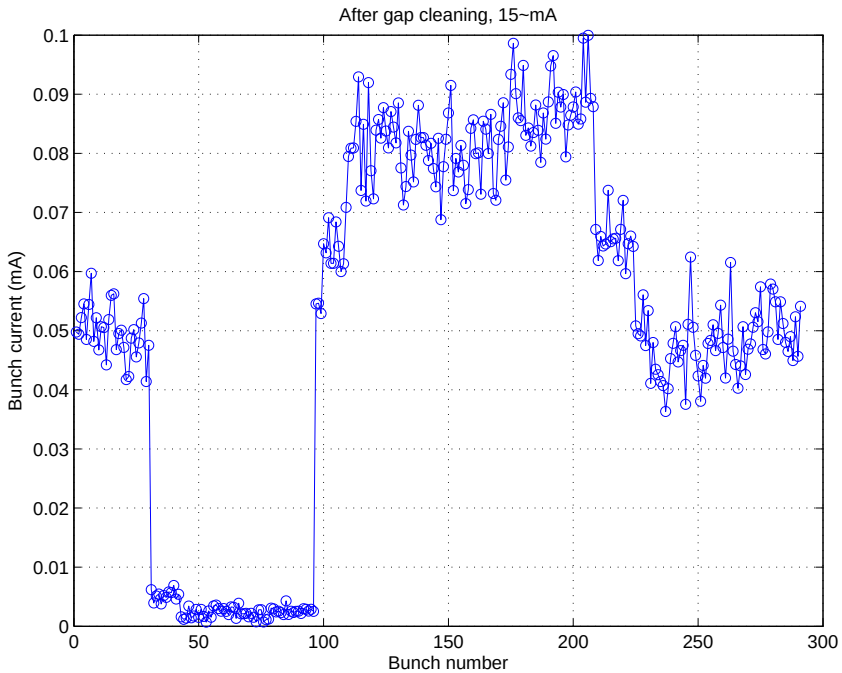

- Use the longitudinal systems as a rudimentary bunch-by-bunch current monitor;
- From a uniform fill we removed 66 bunches, creating a gap;
- Then cleaned out every third bunch;
- Once more, leaving every third bunch in the ring.

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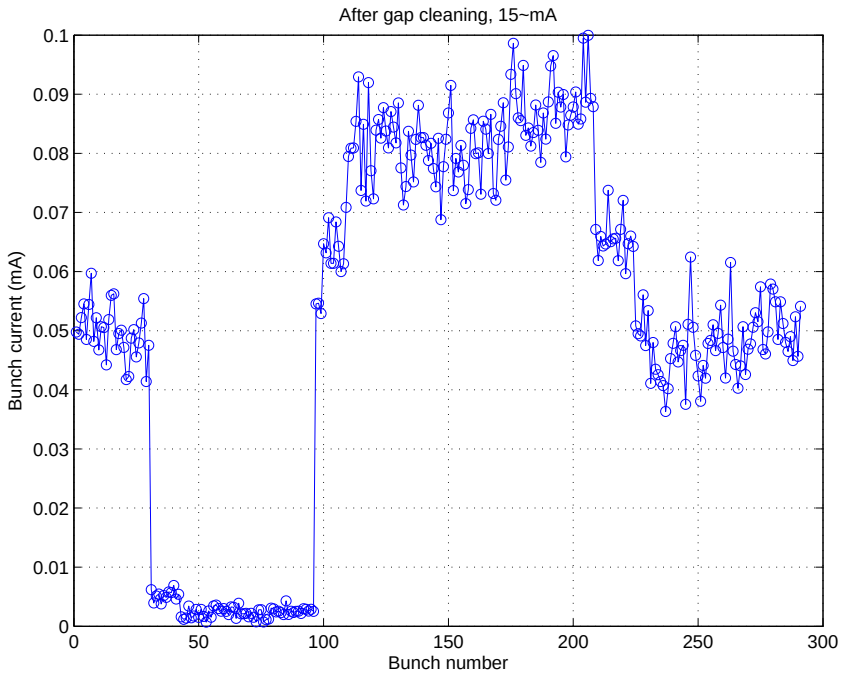

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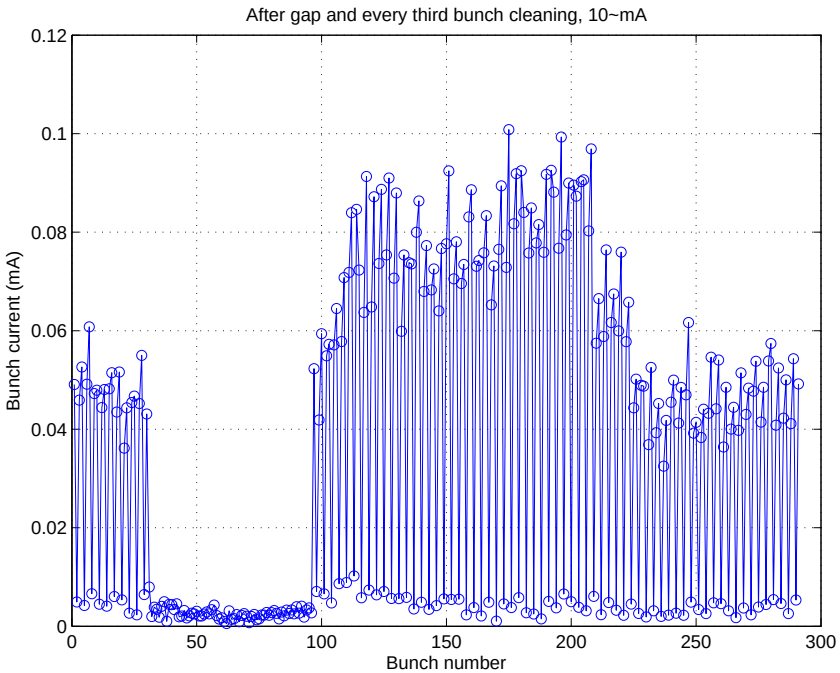

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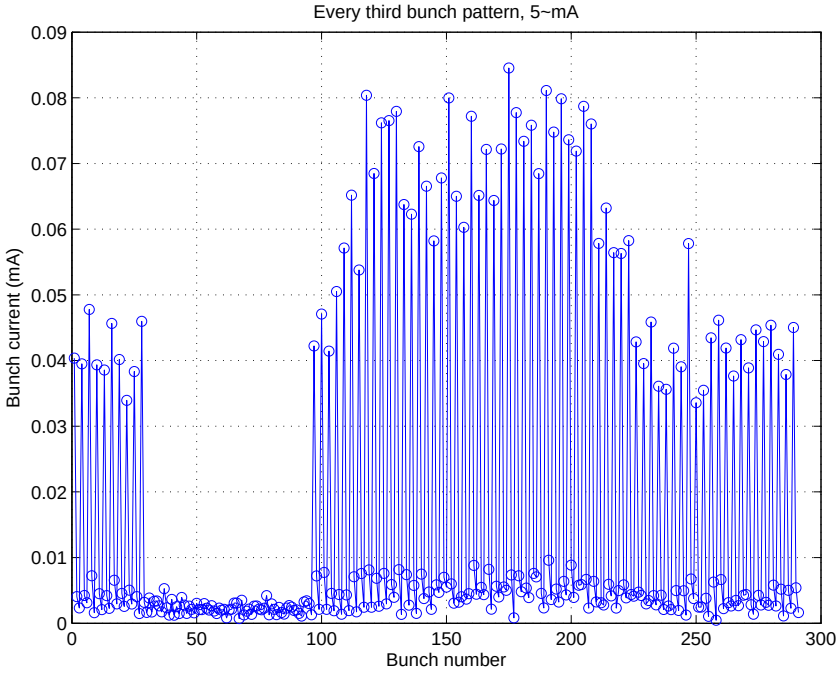

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- Successfully commissioned bunch-by-bunch feedback in the transverse planes;
- Ramping with phase tracking works well, need to explore two/three plane feedback;
- So far only see ion instabilities, higher current studies needed;
- Demonstrated real-time tune measurement, bunch cleaning, injection diagnostics;
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- Longitudinal feedback;
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- Stable external fiducial;
- Calibration — getting physical amplitudes;
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