Tests of FPGA-based transverse feedback prototype in DAΦNE

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Outline

I. Feedback prototype description

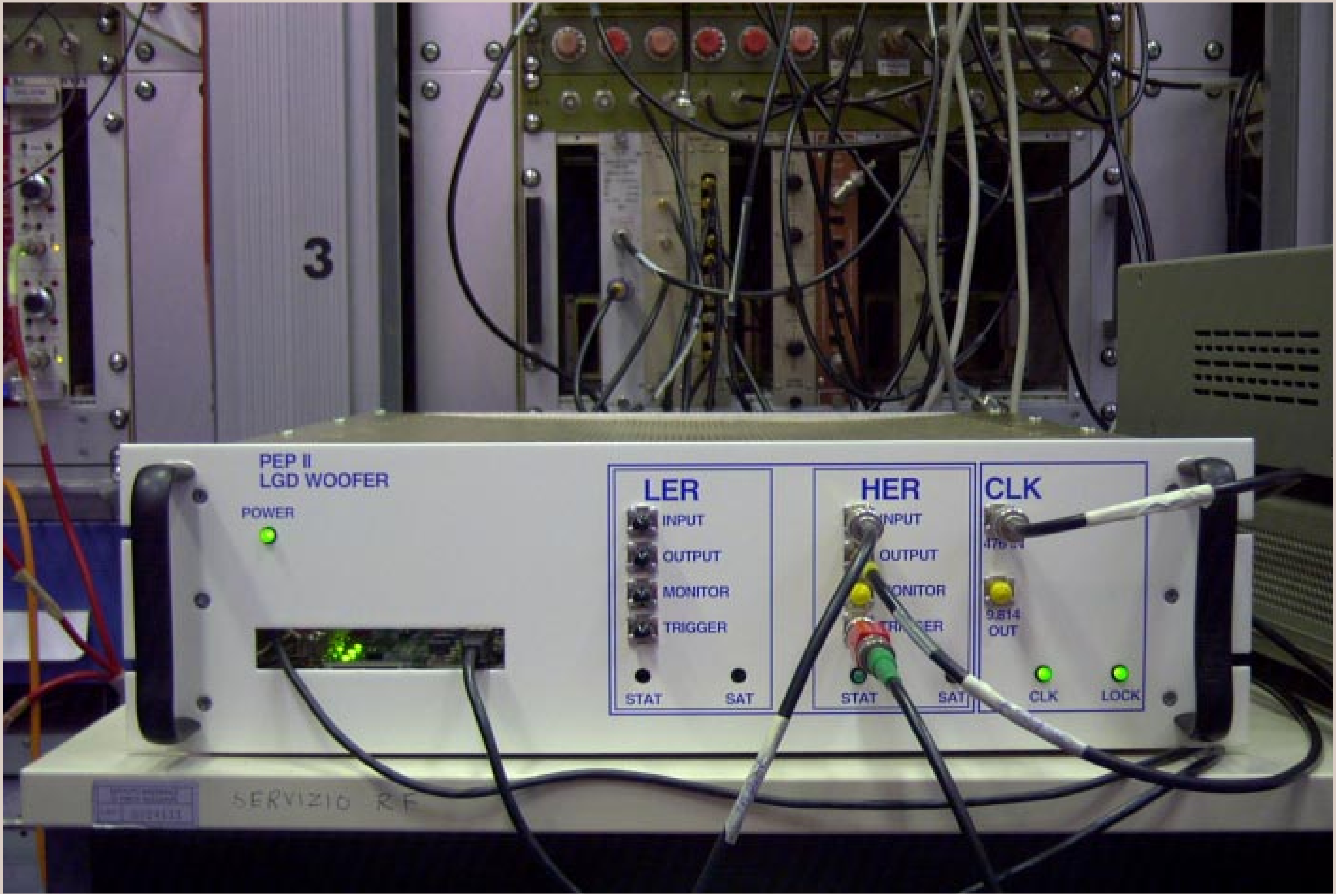
- Hardware structure
- Control interface
- Capabilities

II. Measurement results

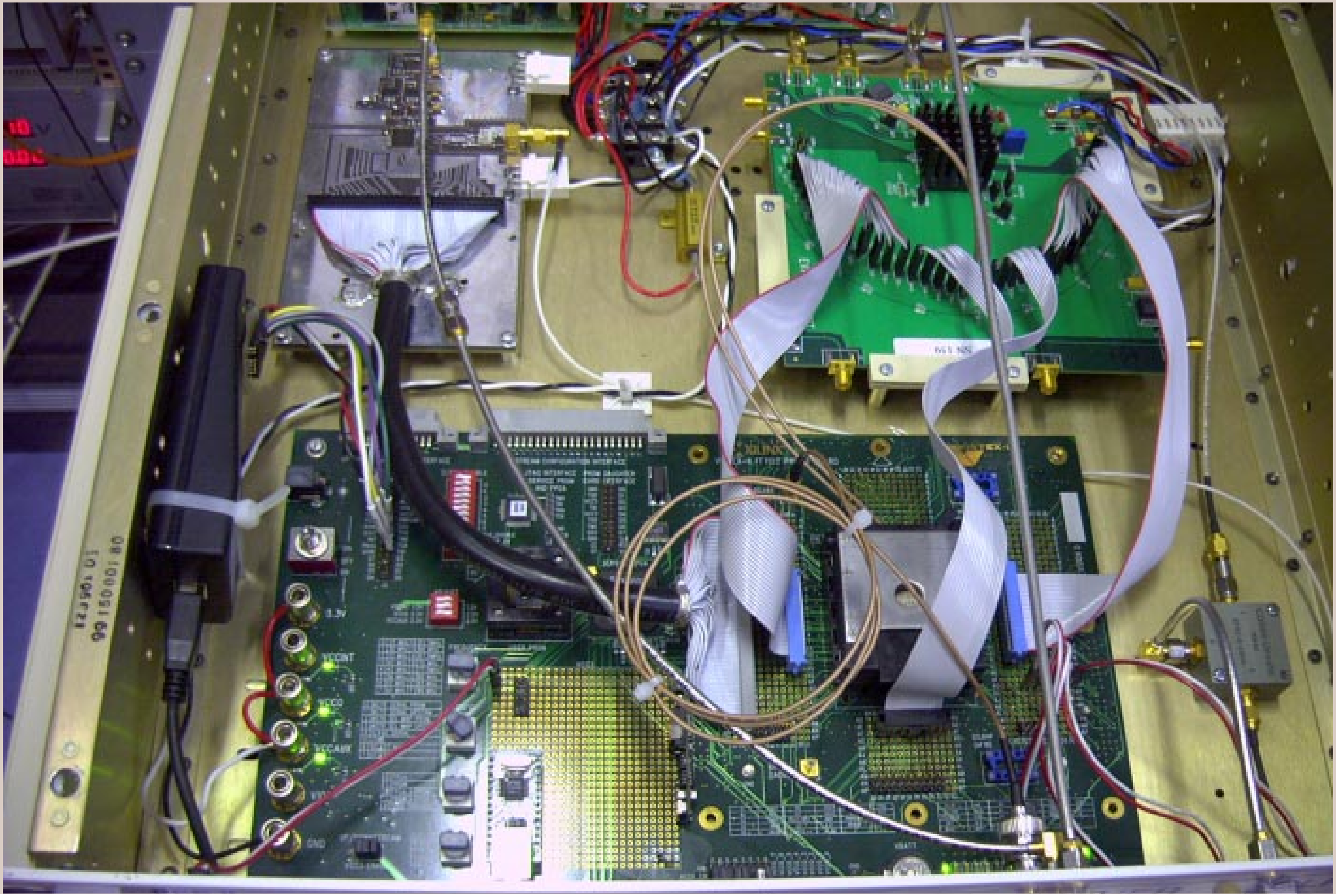
- Growth rate measurements
- Damping rate measurements
- Injection transients

III. Conclusions

What is the prototype?



Inside the prototype



Functionality

A 500 MHz bunch-by-bunch processing channel

8-bit ADC (MAX108), 12-bit DAC (MAX5886)

8-tap FIR filter with 16-bit coefficients, 2 selectable coefficient sets

Shift gain, saturation, adjustable one-turn delay

128 kBytes of data acquisition memory (1092 turns)

Internal or external trigger with arming

Grow/damp support - at the start of the recording system can switch to the second coefficient set for a predefined interval

Hold-off support - switch to the second coefficient set, but wait for some time before starting to record. Very useful for slowly growing transients.

DAC test pattern generator built in

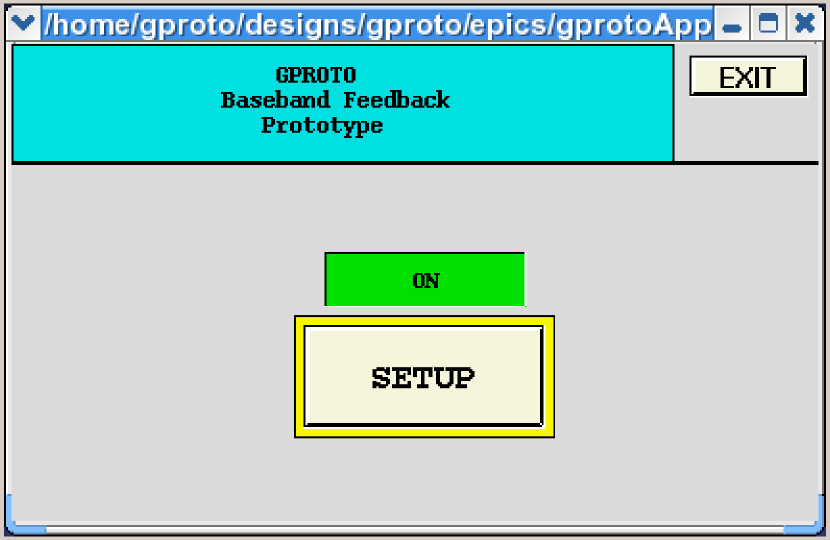
Status monitoring: RF clock missing, internal DLL unlocked, filter saturation

Control interface: top panel

A very simple top-level panel with only one button: ON/OFF

Status summary in color around the SETUP button

- Green - no warnings
- Yellow - saturation
- Red - USB I/O error, missing clock, DLL unlocked



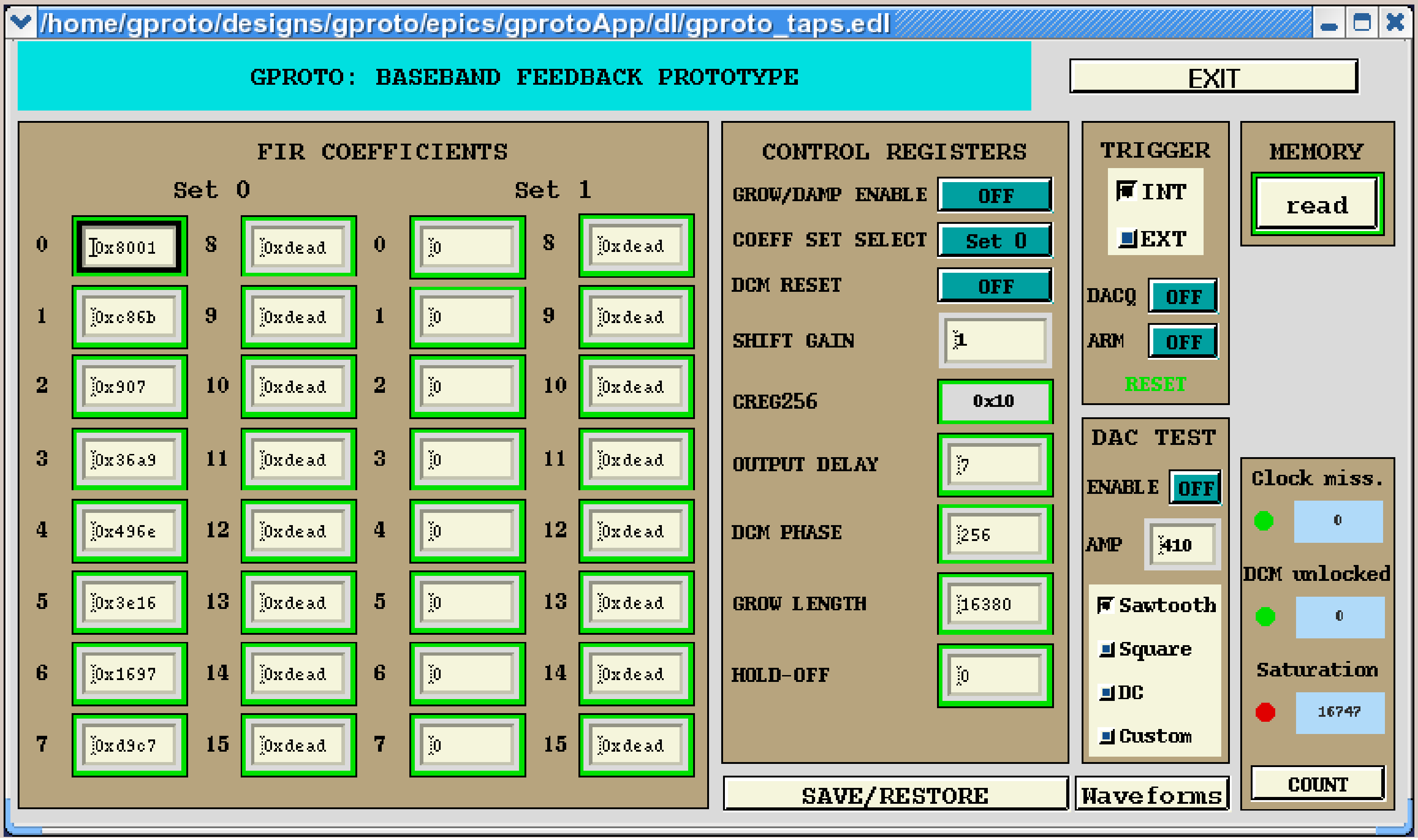
Control interface: main panel

Filter control: coefficients, gain, delay, set select

Data acquisition: grow/damp, triggers, memory readout

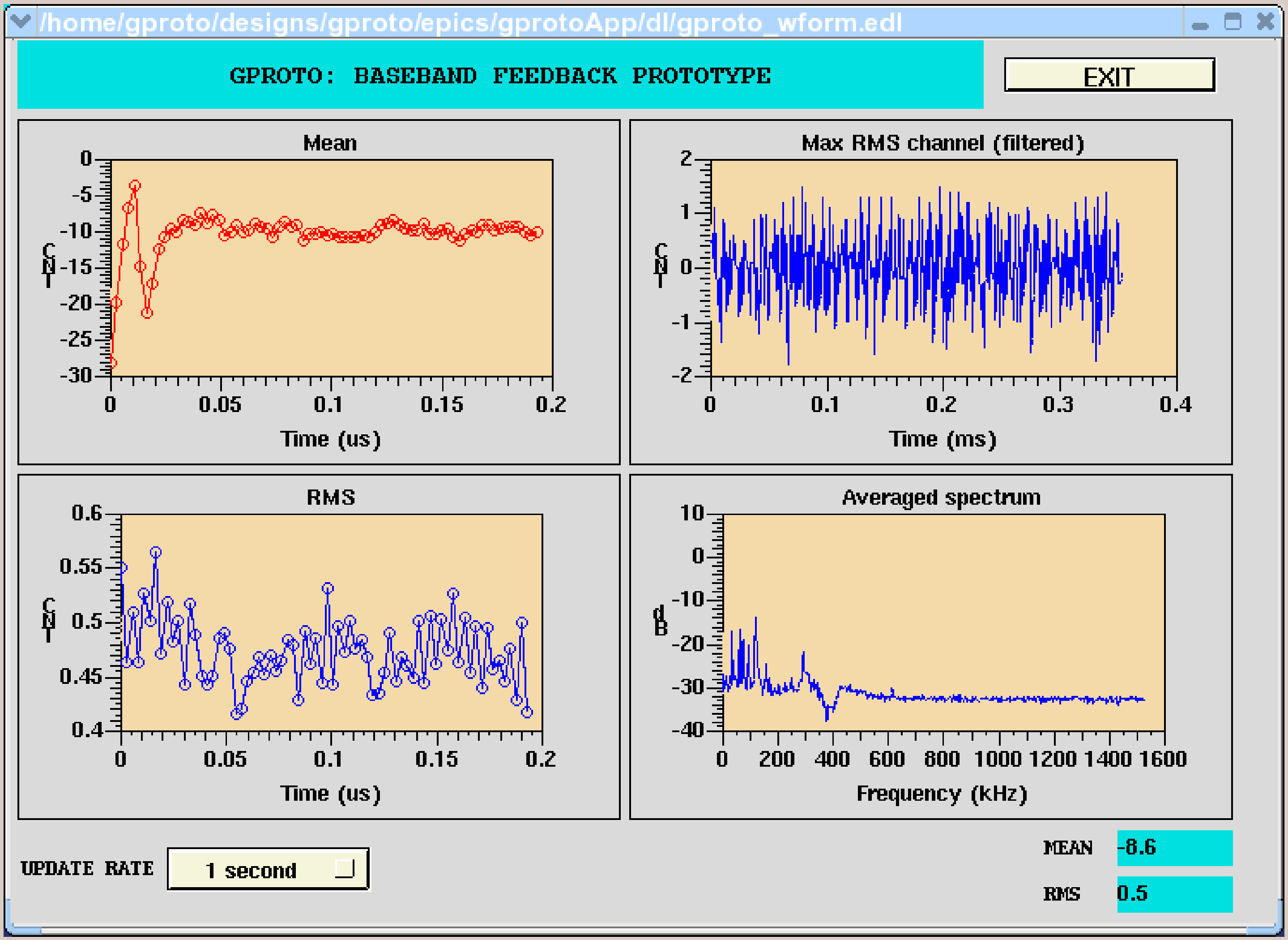
DAC test pattern generator

Status monitoring: LEDs and counters



Control interface: real-time diagnostics

Plot mean and RMS around a turn, oscillation of the channel with largest RMS, averaged bunch spectrum. Update rates up to 1 Hz are supported



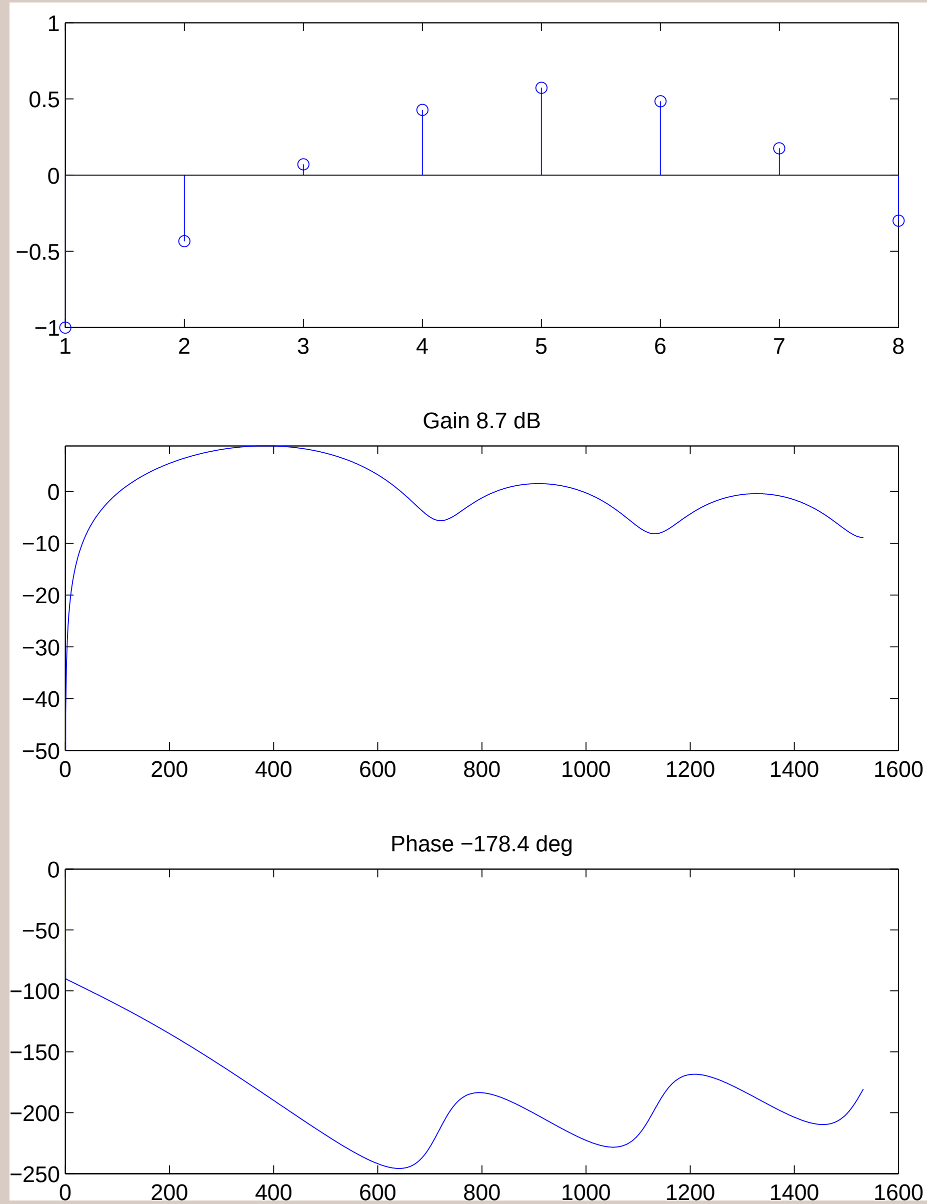
Feedback filter response

DC and low-frequency rejection

Filter gain at ν_x - 8.7 dB

Adjustable phase response to match the phase advance between the BPM and the kicker

Flexible - other design approaches can be used to emphasize desired characteristics



Grow/damp measurements

Traditional unstable dynamic system characterization approach

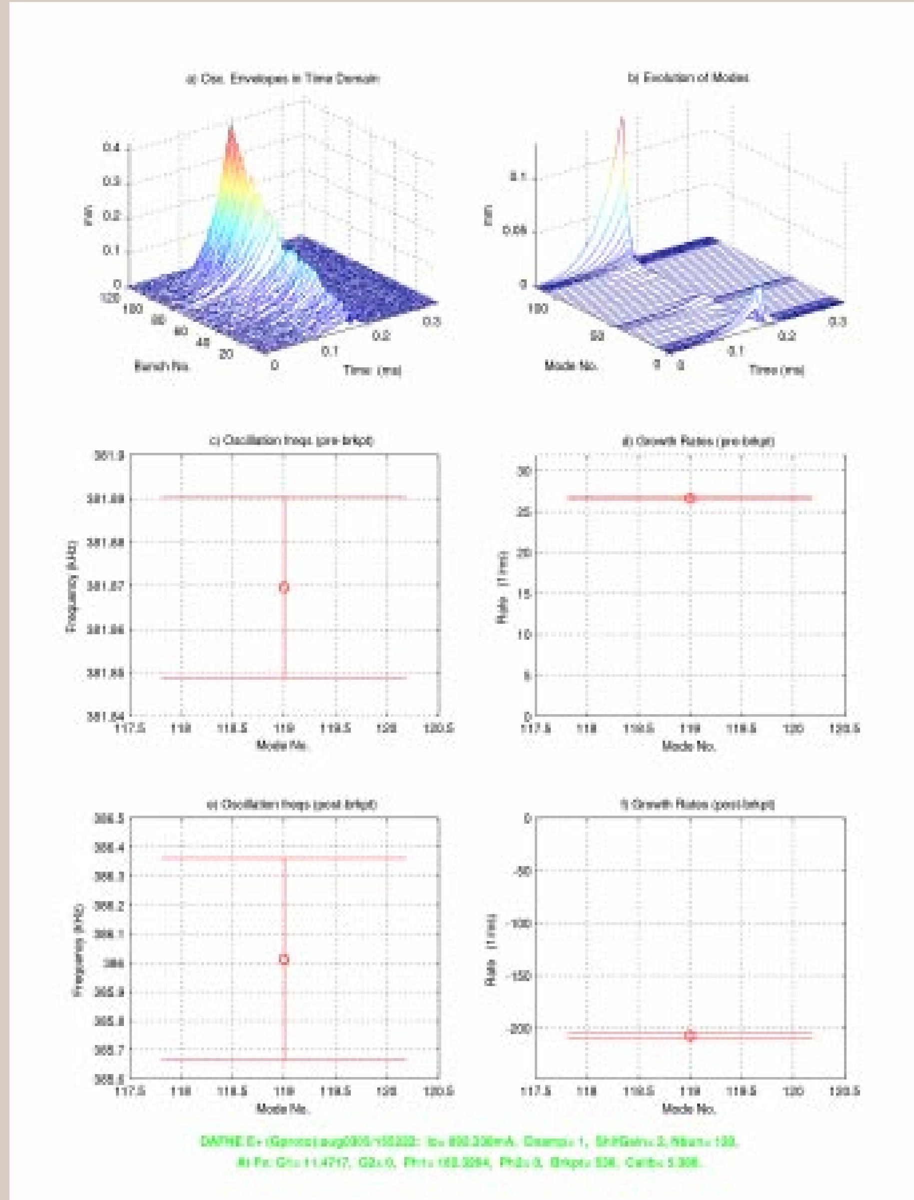
A typical grow/damp pattern showing oscillation amplitudes increasing towards the tail of the train. Peak centroid oscillation amplitudes reach 0.4 mm

Allows one to extract open and closed-loop eigenvalues for the unstable mode

Mode -1 unstable - consistent with resistive wall or electron cloud

An example illustrated here shows a growth rate of 26 ms^{-1} and an order of magnitude faster damping rate of 207 ms^{-1}.

Tune shift from open to closed loop is moderate: 4 kHz out of 384 kHz



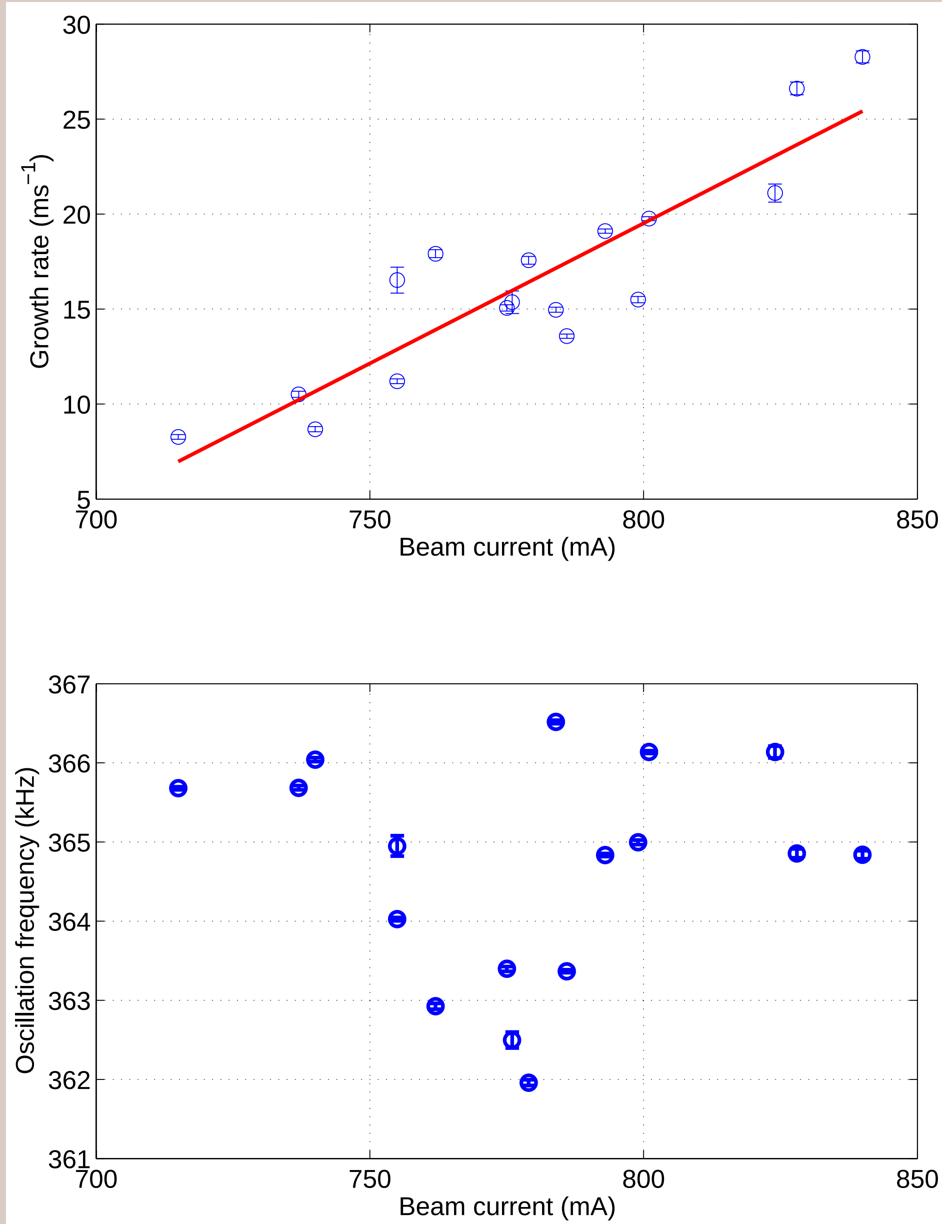
Growth rates and tunes vs. current

Data from the measurements on the 27th of July

Nearly linear scaling of the growth rates with beam current. Assuming linear behavior expect a threshold at 677 mA.

Unclear tune shift behavior - no overall slope

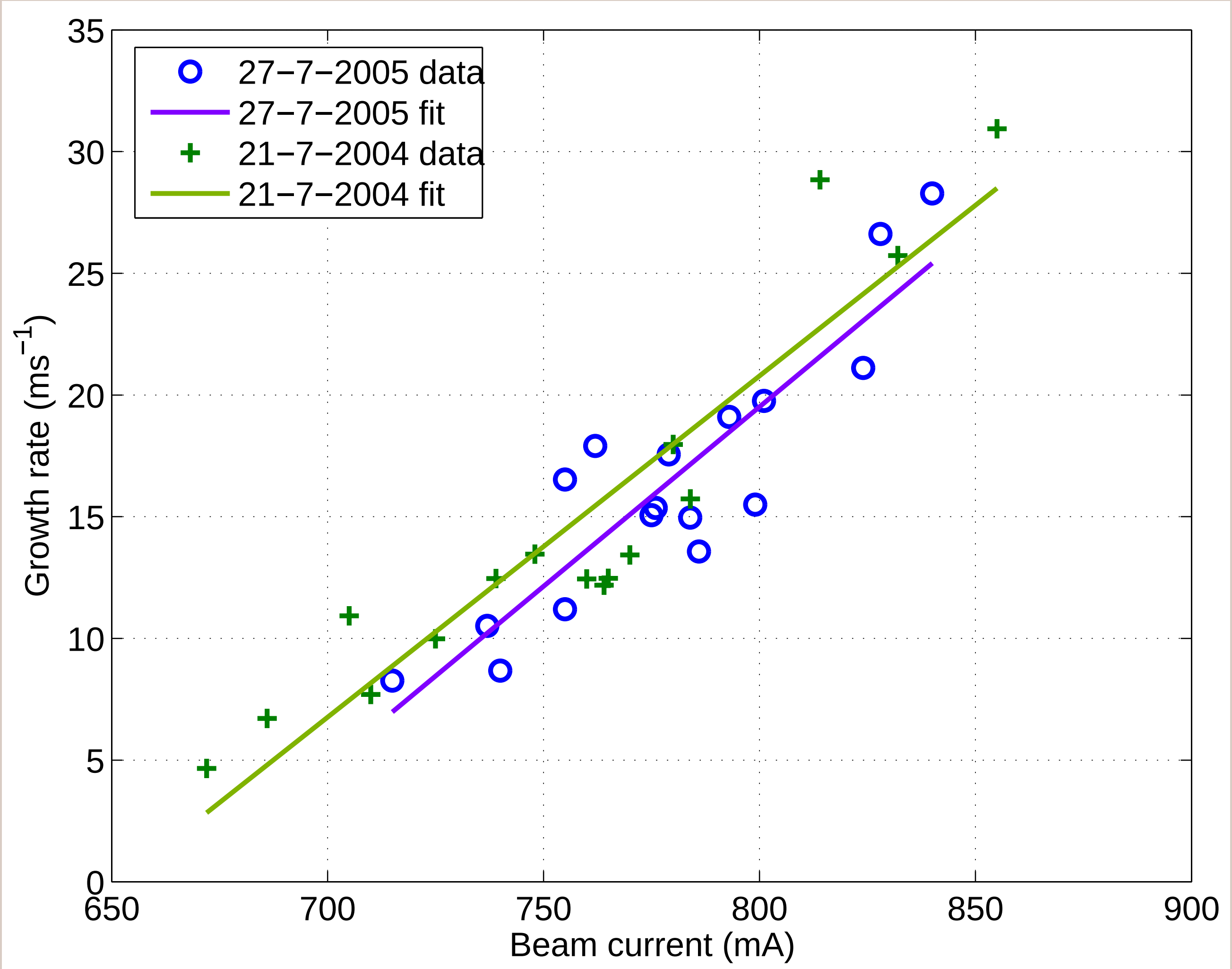
Is the dip in tune between 750 and 800 mA real?



Growth rates and tunes vs. current: a comparison to 2004

Growth rate comparison: a year ago and now

Growth rates are nearly the same.



Growth rates and fill patterns

Just like a year ago we see that the growth rates and tunes strongly depend on the pattern.

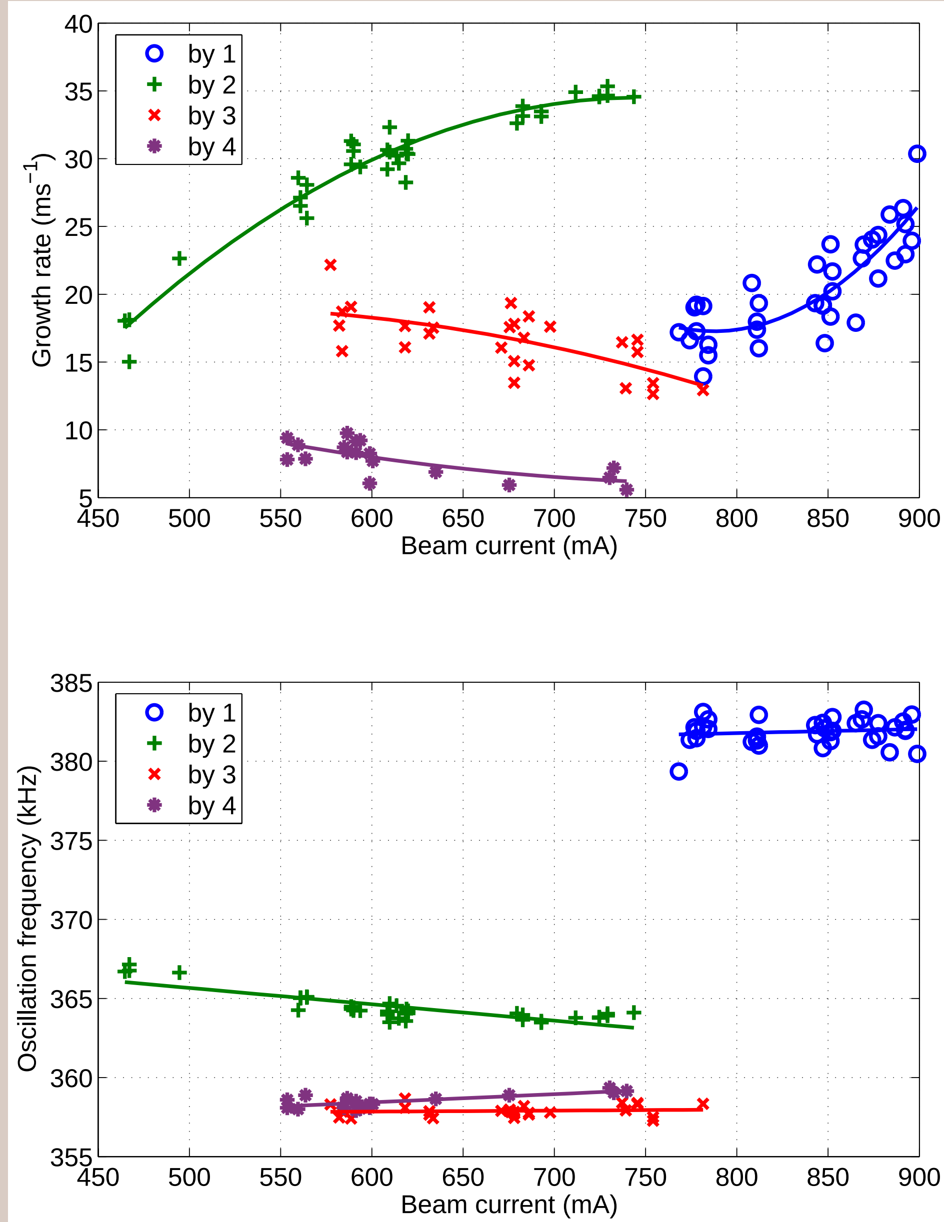
Large positive tune shift in the by-1 pattern (24 kHz or 0.008)

Much smaller shift in the by-2 pattern (6.5 kHz or 0.002)

No shift in by-3 and by-4 patterns

Growth rate curve saturates in the by-2 pattern

Growth rates decreasing with in the by-3 and by-4 patterns

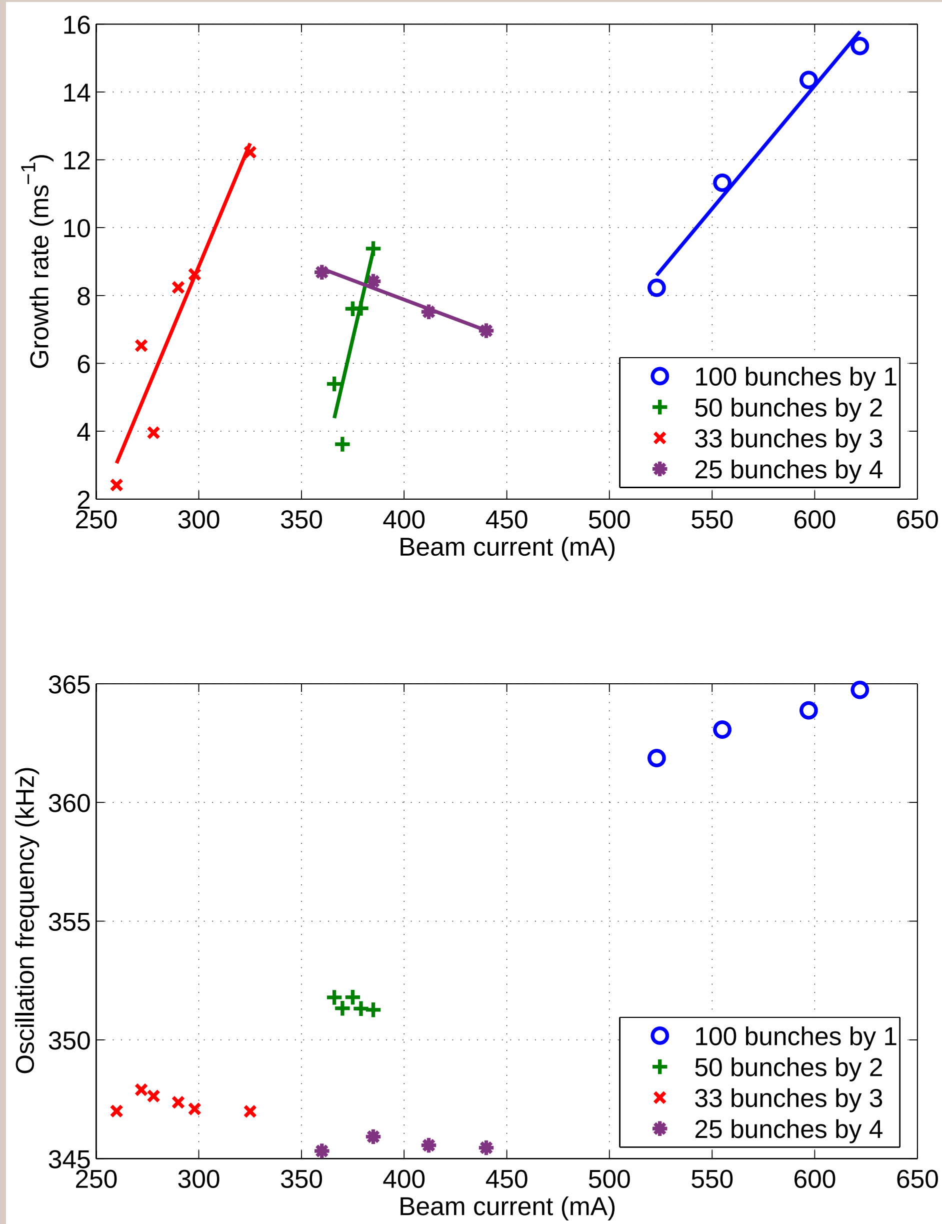


Growth rates and fill patterns: 2004

Similar behavior in the by-1 pattern

Much faster growth in by-2 and by-3

By-4 pattern is slower, similar to current behavior



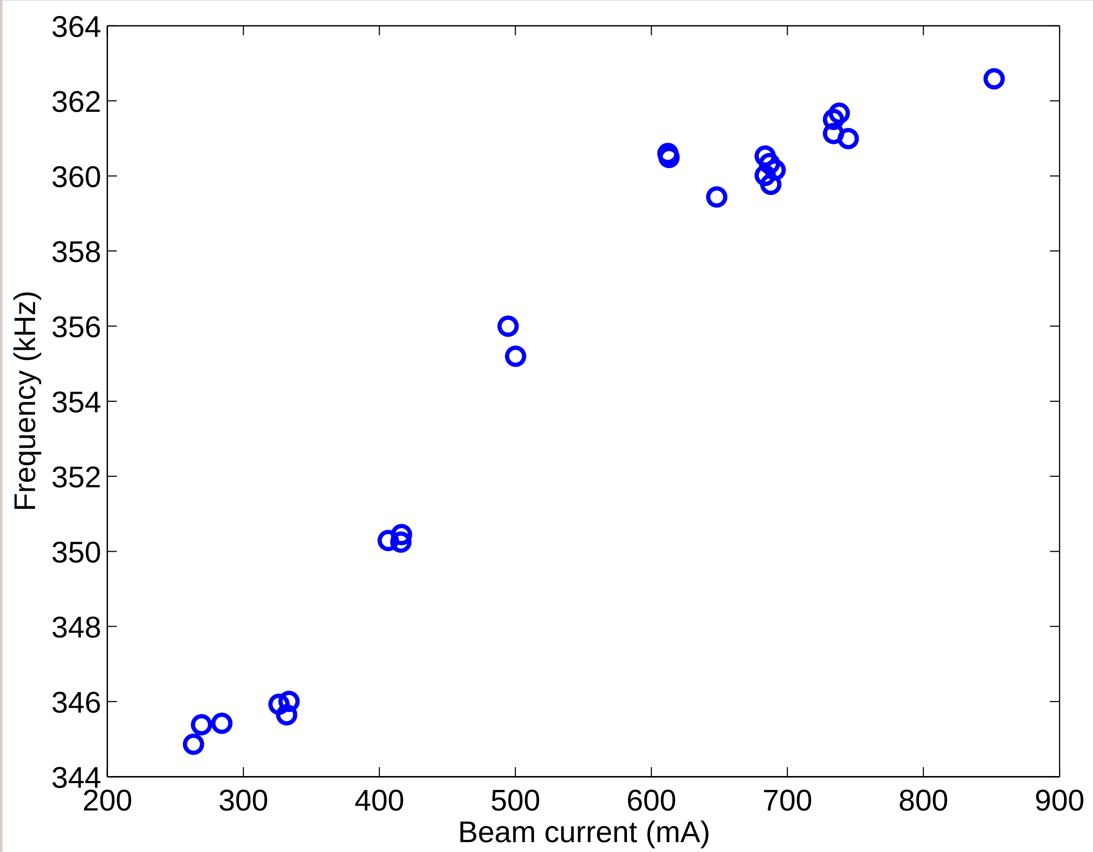
Horizontal tune vs. beam current

Measurement made late in the day

A different machine - one of the electron ring wigglers has been turned on

Open-loop measurements in all cases

- Below the threshold (600 mA) the frequency is extracted as the centroid of the small tune line
- Above the threshold the frequency is that of the growing eigenmode -1



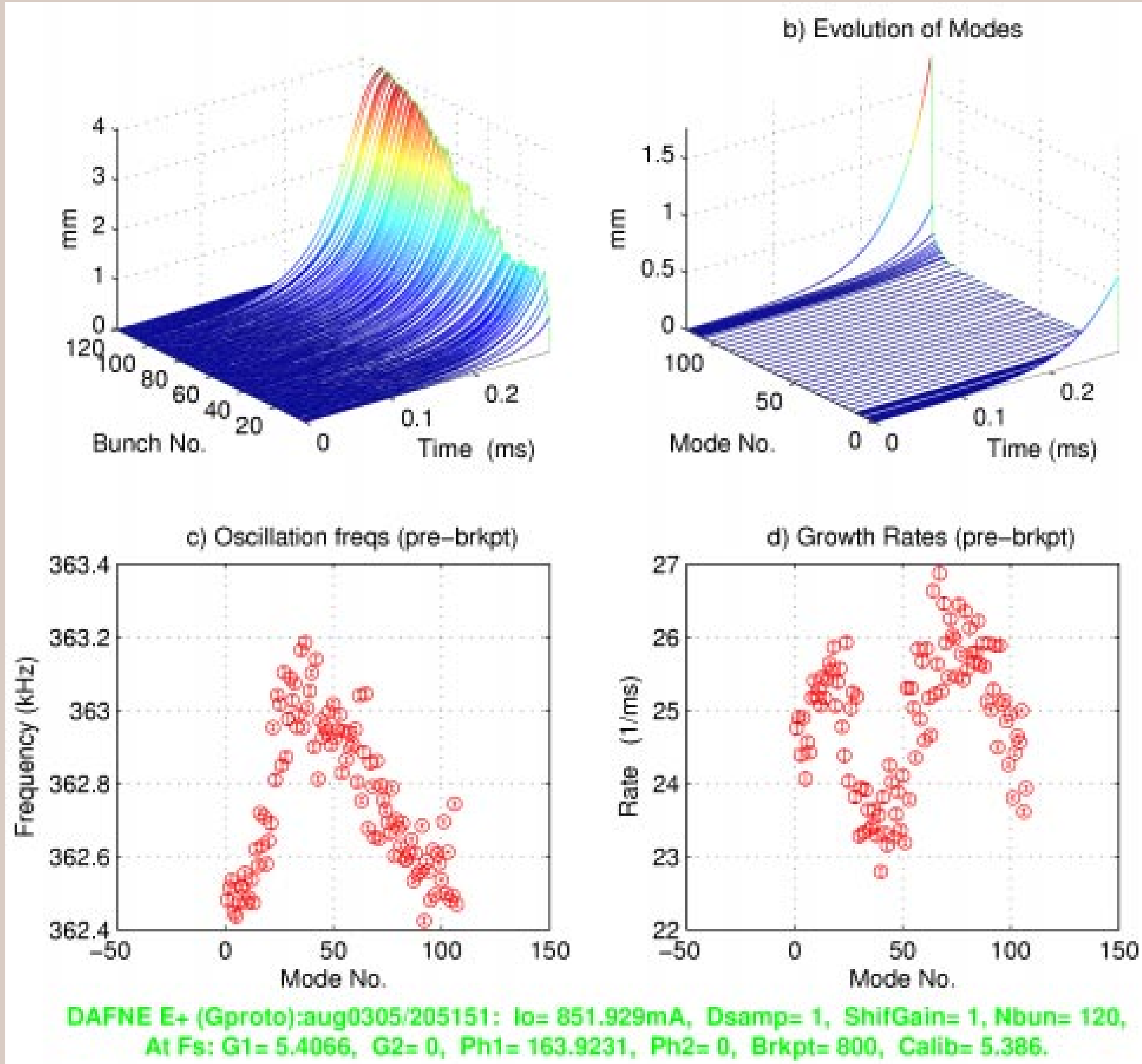
A fast increase in tune between 350 and 600 kHz, then saturation

Tune and growth rate variation along the train

Here we fit complex exponentials to bunch oscillation trajectories

Evidence of small tune shift along the train as well as some growth rate modulation

More analysis is needed.

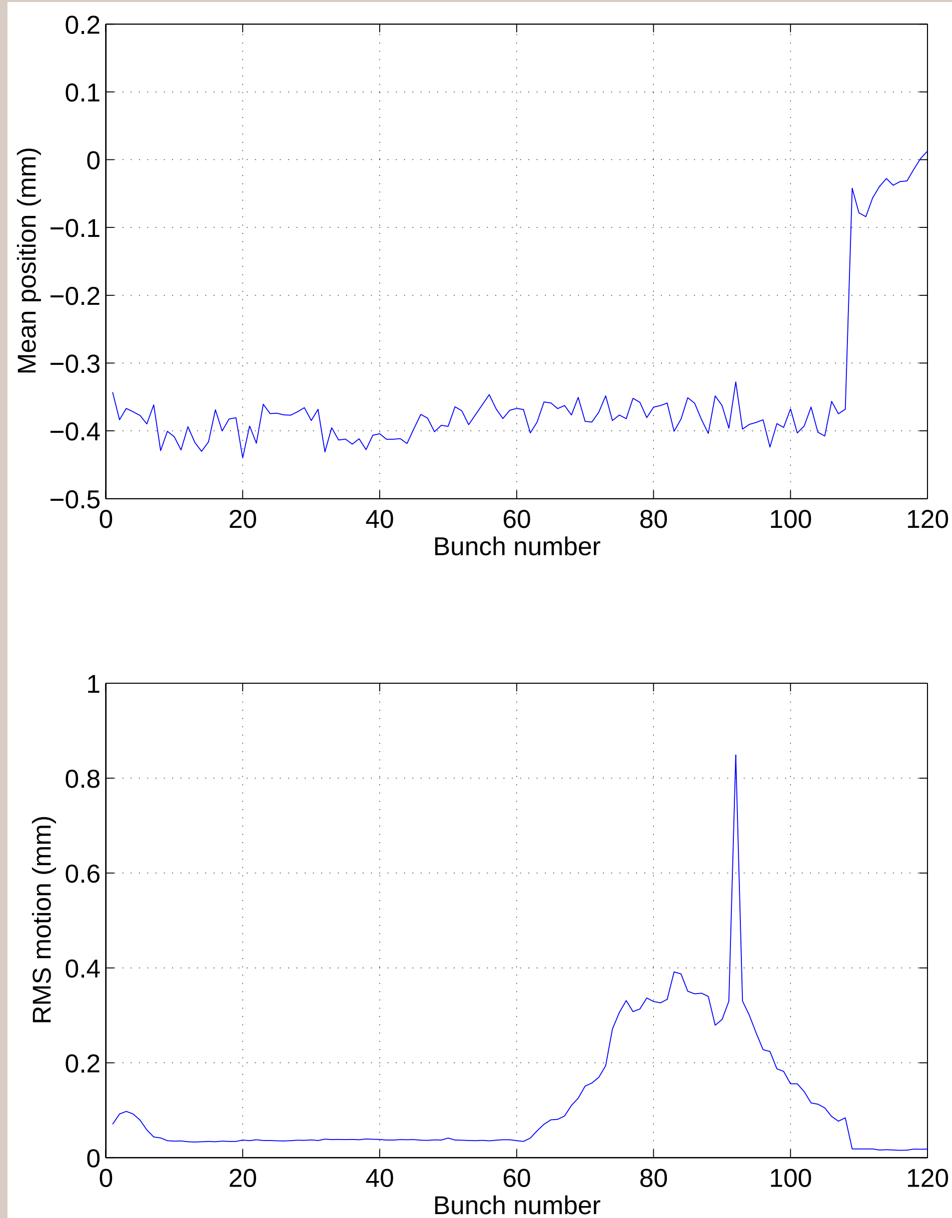


System limits: injection transients

External trigger from injection pulse

Taken at 580 mA, 108 bunches filled

Injection into bunch 92

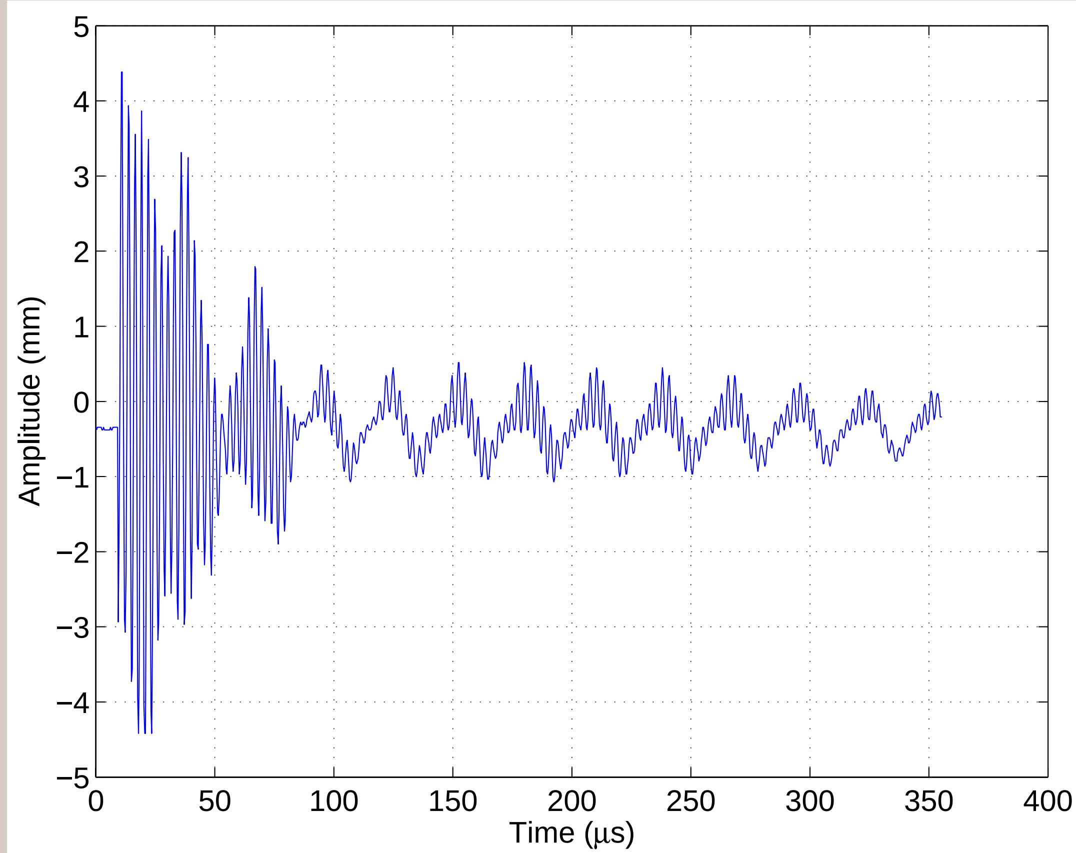


System limits: injection transients

Injected bunch has very large oscillation amplitude of 4.5 mm

Motion actually saturates the feedback ADC

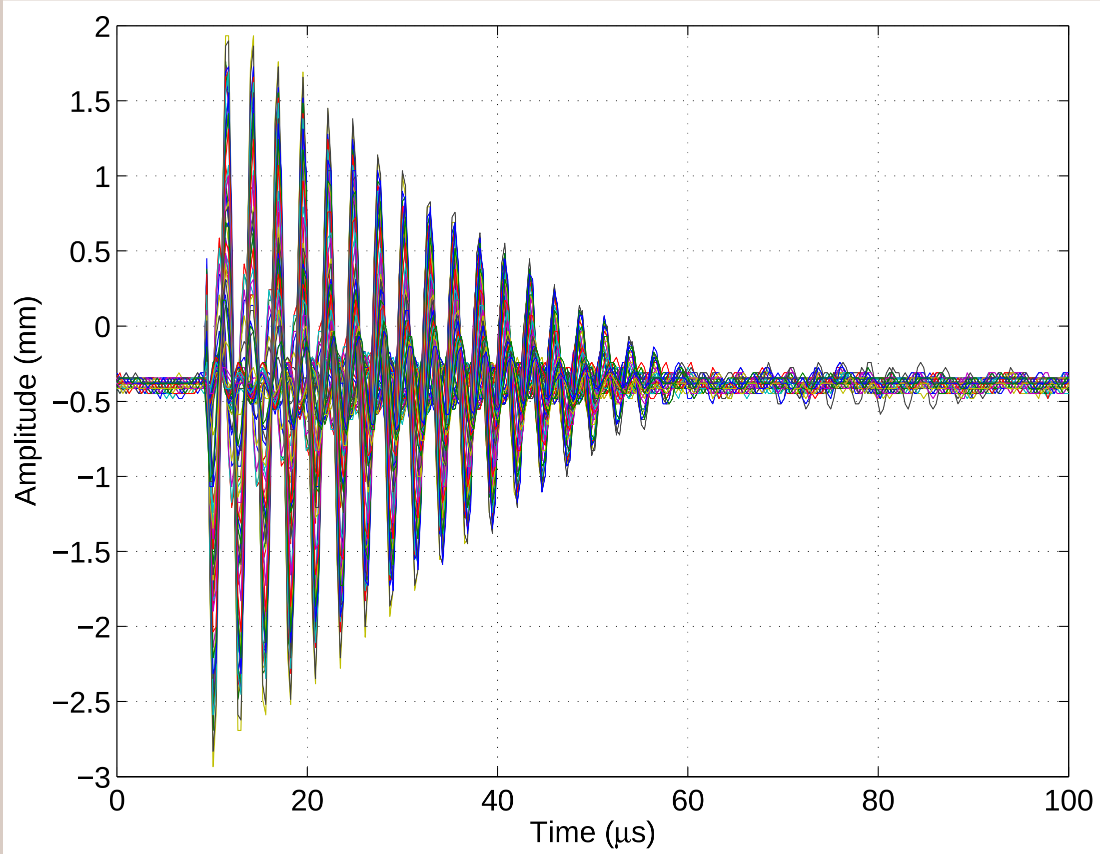
Evidence of longitudinal oscillation (low frequency)

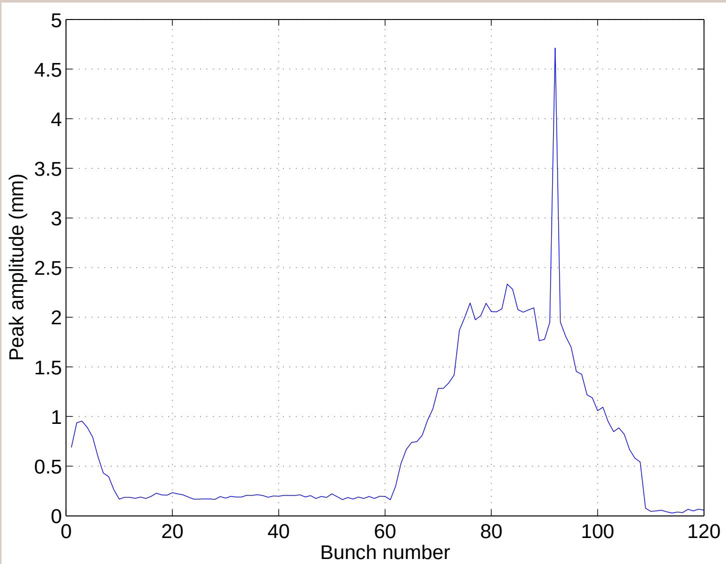


System limits: injection transients

The rest of the train is also strongly excited

Saturated feedback produces linear damping to the noise floor





Summary

Tests of the feedback prototype have been very successful. It took us less than two hours to get the prototype running and to reach high beam currents.

8-tap FIR filter is sufficient to provide strong transverse damping and phase control

Diagnostic features of the system as well as the existing tools make commissioning and tuning of such feedback very quick

Horizontal growth rates in the positron ring show variation with the bunch pattern that is inconsistent with the simple resistive wall model

Behavior of the beam (growth rates and tune shifts) points to the electron cloud as the instability source

The behavior is improved since the last year pointing to changes in the electron cloud, possibly due to scrubbing

Injection transients excite large amplitudes in both injected and stored beam

Reducing stored beam excitation should help in raising the maximum beam current