# 2007 goals and feedback systems

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# Outline

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- Growth rates due to the cavity HOMs
- Technical solutions and the limits

III. Transverse plane

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- HER vertical measurements
- Transverse stability summary

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# Parameters for 2007

RF parameters from J. Seeman

| Ring | Date | I, mA | $V_{rf}$, MV | Number of cavities | Momentum compaction | Synchrotron frequency, kHz |
|---|---|---|---|---|---|---|
| LER | 7/2004 | 2450 | 3.8 | 6 | 0.00123 | 3.9 |
| LER | 11/2006 | 4500 | 7.7 | 10 | 0.00123 | 5.55 |
| HER | 7/2004 | 1590 | 16.5 | 26 | 0.00241 | 6.57 |
| HER | 11/2006 | 2200 | 18.7 | 26 | 0.0017 | 6.01 |

Main issues

LER

- 84% higher beam current
- 67% more impedance

HER

- 38% more beam current

# Station power requirements and gap transients

A study of per station power requirements and synchronous gap transients using the large-signal operating point code. Assumed by-2 fill pattern with 2.5% gap.

| Ring | Date | I, mA | $V_{rf}$, MV | Power per station, kW | Gap transient peak-to-peak amplitude, deg@RF | Maximum detuning, kHz |
|---|---|---|---|---|---|---|
| LER | 7/2004 | 2450 | 3.8 | 696 | 13.8 | 204 |
| LER | 12/2006 | 4500 | 7.7 | 858 | 21.5 | 322 |
| HER | 7/2004 | 1590 | 16.5 | 930 | 9.4 | 158 |
| HER | 12/2006 | 2200 | 18.7 | 1035 | 11.3 | 168 |

Shorter abort gap in the LER (1.25%) will reduce gap transient to match HER.

HER will need all SLAC klystrons to get the required power. Even then the klystrons will need to operate quite far into saturation.

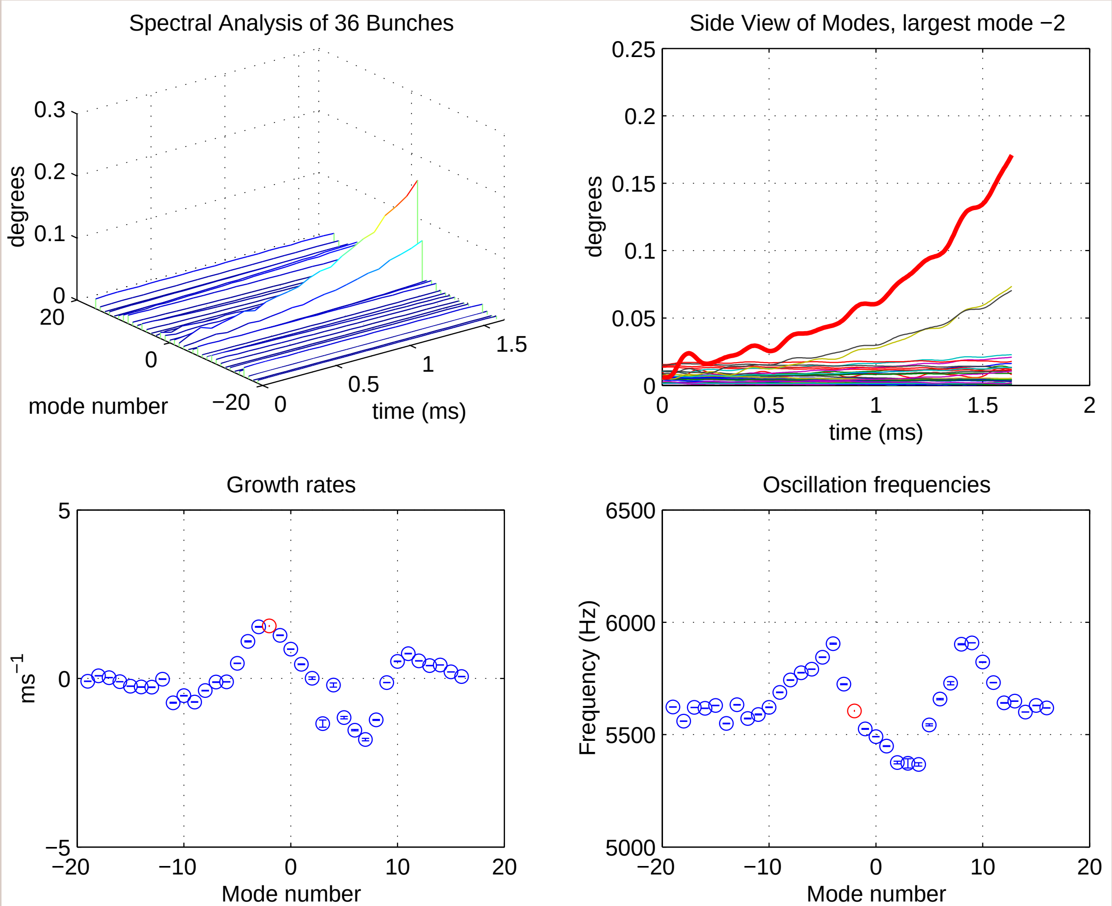
Klystron linearizer needs extra headroom for proper operation as compared to the bare klystron. Exact amount of the necessary headroom is to be characterized during beam tests in run 5.

# Growth rates due to the cavity fundamental mode

Time-domain simulation of the LER:

- 10 cavities
- 7.7 MV gap voltage
- 323 kHz detuning
- Nominal LLRF settings
- No klystron saturation

Fastest growing mode is -2 with the rate of 1.6 $ms^{-1}$.

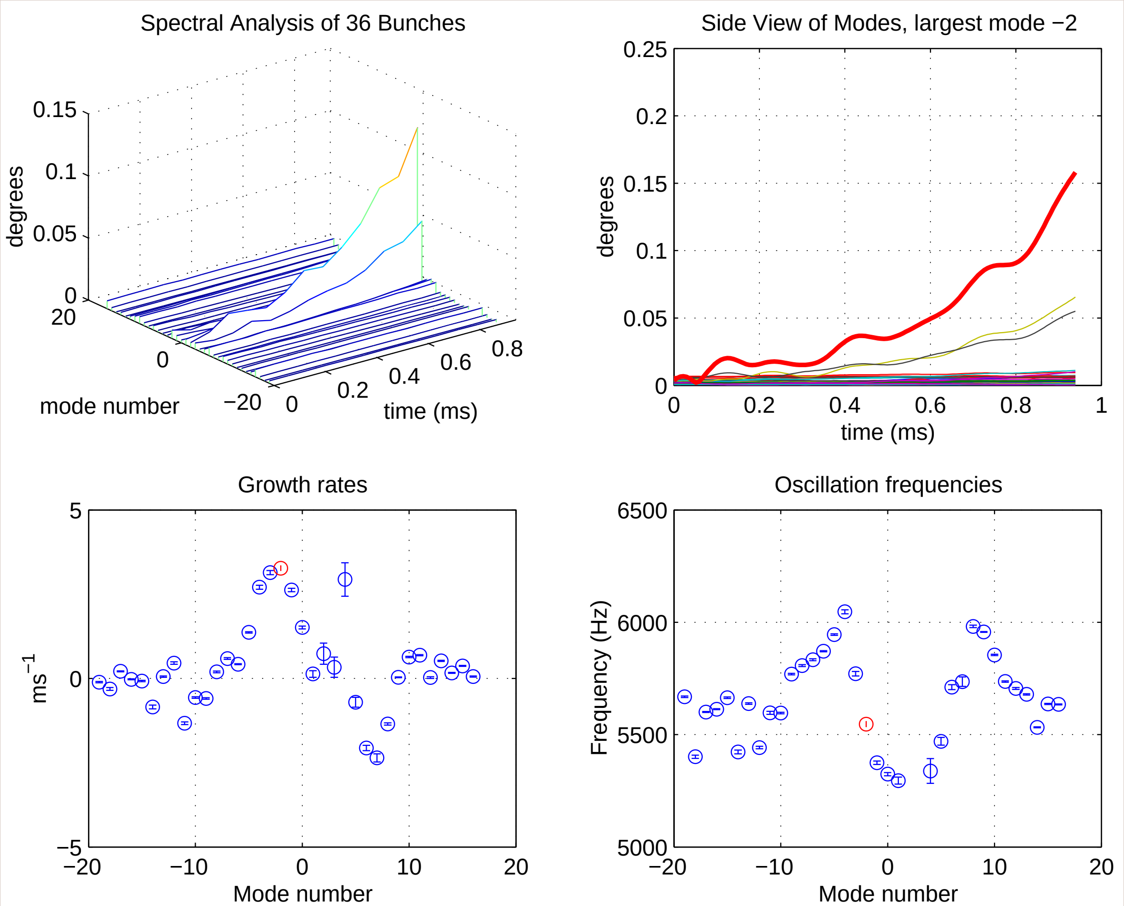


# Growth rates due to the cavity fundamental mode

Time-domain simulation of the LER:

- 10 cavities
- 7.7 MV gap voltage
- 323 kHz detuning
- Nominal LLRF settings
- Klystron at 80% saturation

Fastest growing mode is -2 with the rate of 3.2 $ms^{-1}$.

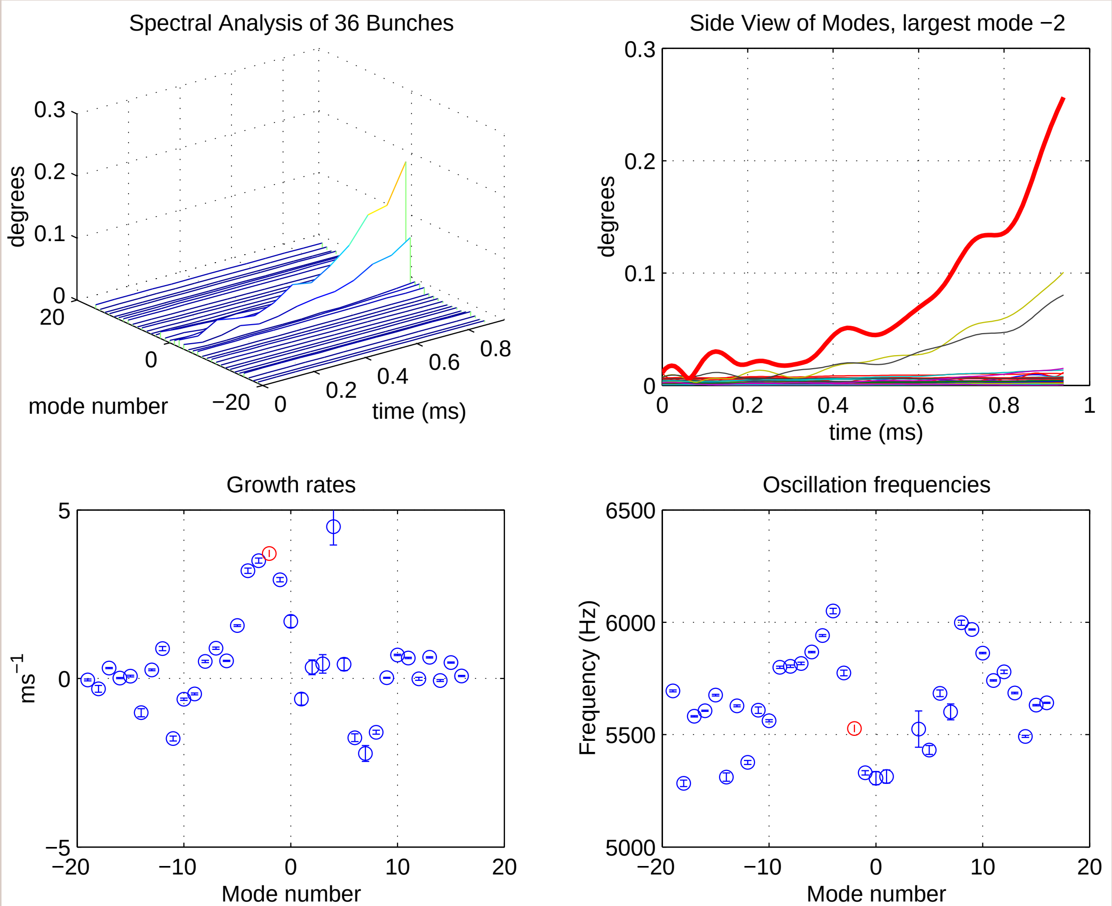


# Growth rates due to the cavity fundamental mode

Time-domain simulation of the LER:

- 10 cavities
- 7.7 MV gap voltage
- 323 kHz detuning
- Nominal LLRF settings
- Klystron at 85% saturation

Fastest growing mode is -2 with the rate of 3.7 $ms^{-1}$.

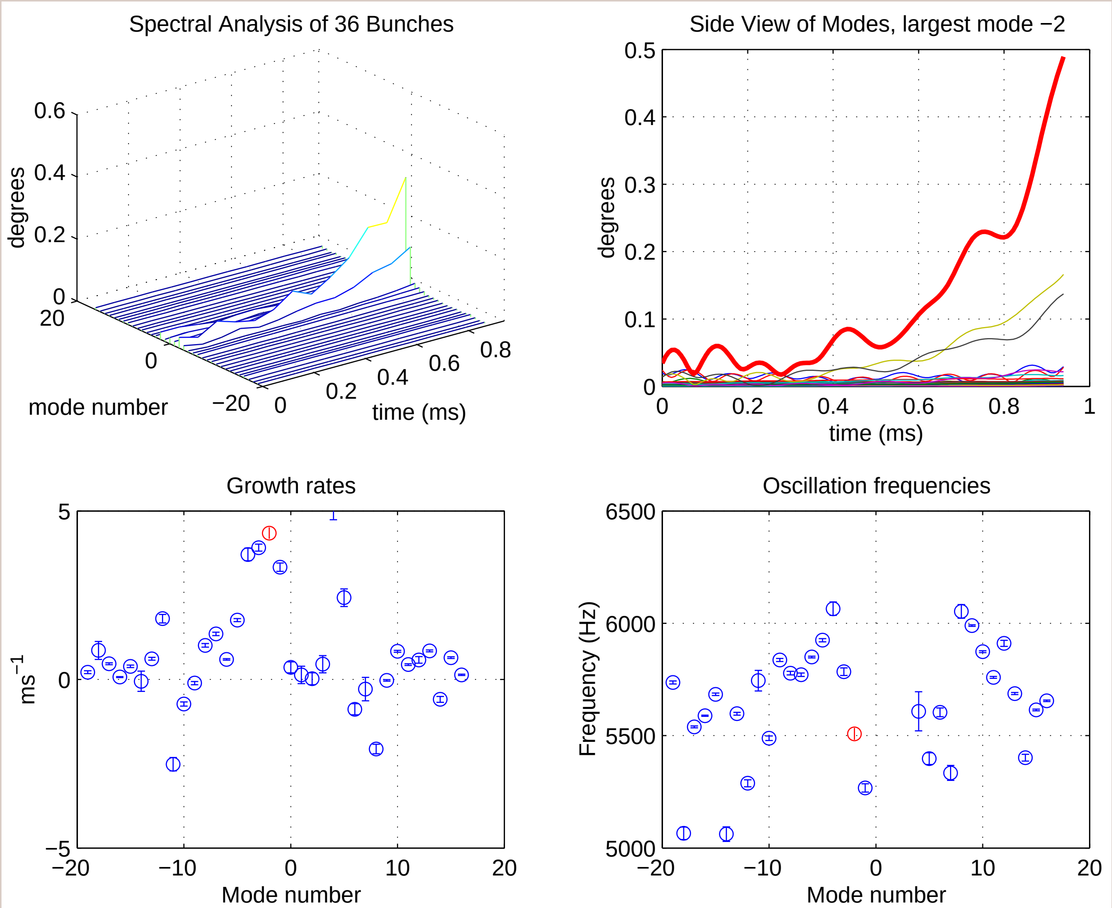


# Growth rates due to the cavity fundamental mode

Time-domain simulation of the LER:

- 10 cavities
- 7.7 MV gap voltage
- 323 kHz detuning
- Nominal LLRF settings
- Klystron at 90% saturation

Fastest growing mode is -2 with the rate of 4.3 $ms^{-1}$.

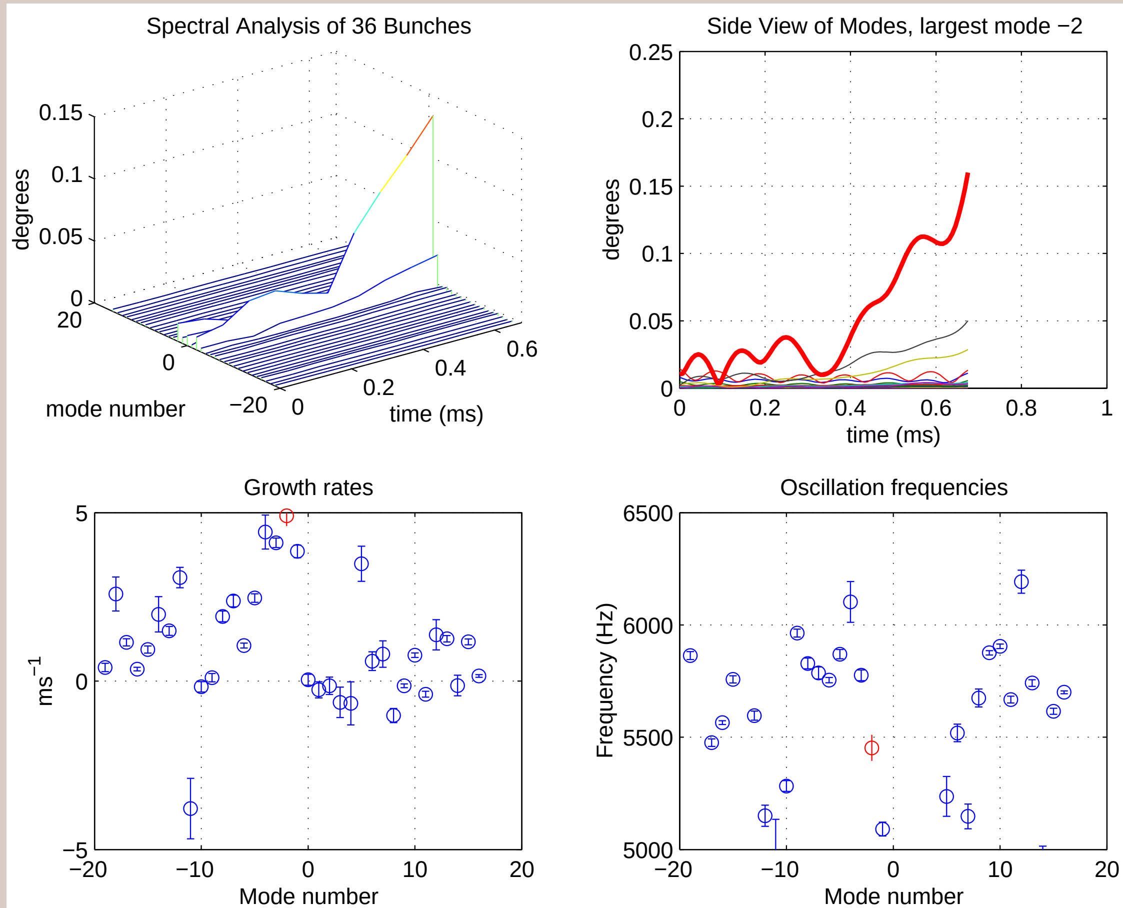


# Growth rates due to the cavity fundamental mode

Time-domain simulation of the LER:

- 10 cavities
- 7.7 MV gap voltage
- 323 kHz detuning
- Direct loop gain 3dB low
- Klystron at 90% saturation

Fastest growing mode is -2 with the rate of 4.9 $ms^{-1}$.



# Growth rates due to the cavity HOMs

LER

- Measured 0.16 $ms^{-1}$ with 4 cavities at 3 MV, 2 A. Scales to 0.56 $ms^{-1}$ at 4.5A (11/2006 parameters)

HER

- Measured 0.14 $ms^{-1}$ with 26 cavities at 15.4 MV, 980 mA. Scales to 0.2 $ms^{-1}$ at 2.2 A (11/2006 parameters)

Current setup in the HER has a 6 dB gain window with the HOM growth rates around 0.21 $ms^{-1}$.

- Clearly insufficient for controlling the LER at 4.5 A
- Marginal for the HER, especially with current momentum compaction.

# Technical solutions: longitudinal plane

## Low group-delay woofer channel

- Provides roughly 10 $ms^{-1}$ of damping for the fundamental-driven modes.
- Can support stable operation with the growth rates up to 5 $ms^{-1}$.

## Klystron linearizer

- Exact improvement is to be determined
- Preliminary test showed roughly 50% reduction of the growth rates of the low modes.

## Low group delay processing channel (Gboard)

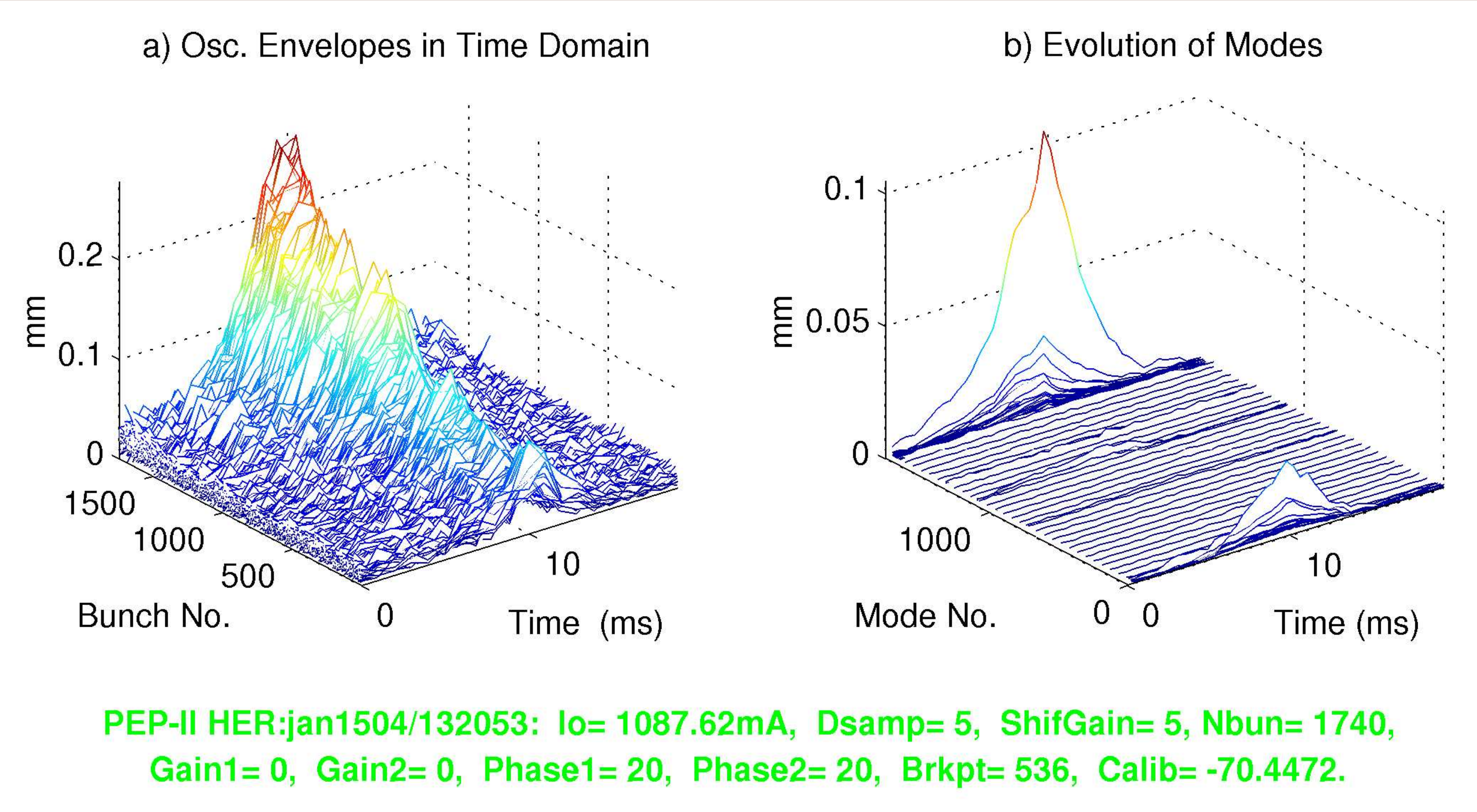
- Provides low group-delay feedback for the HOMs with maximum damping around 10 $ms^{-1}$.
- Eliminates sensitivity of the LFB to the gap transients by using I&Q detection
- Adds longitudinal fault file capability
- Automated parasitic grow/damp monitoring of the instabilities

# Transverse grow/damp measurements

We used the LER LFB to record the transverse motion (X or Y) while controlling an RF switch in the TFB signal path

Low-frequency modes (driven by the resistive wall) grow when the feedback is off.

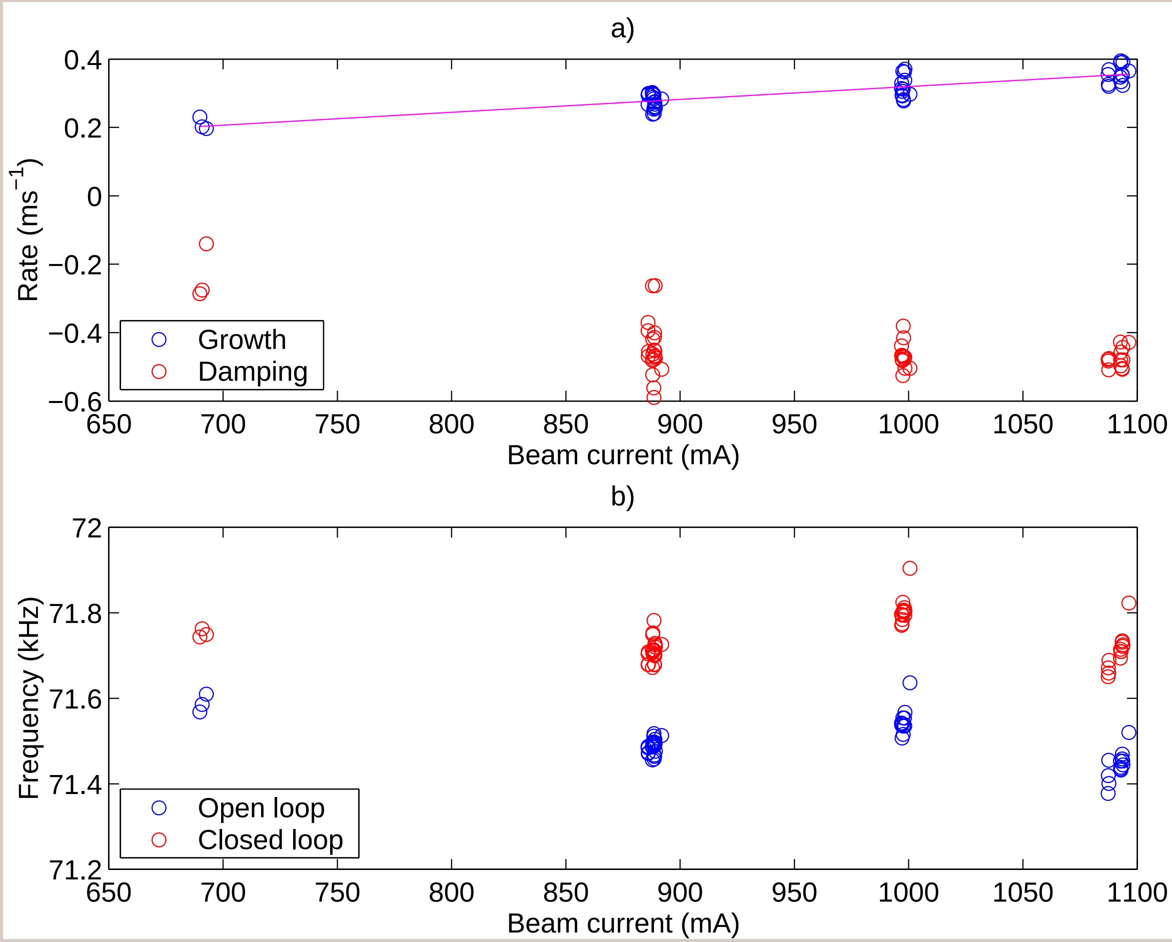
When the switch is turned back on the motion is damped.



# HER horizontal grow/damp measurements

Eigenvalues of mode -1 (resistive wall?).

A linear fit to the open-loop growth rates provides an estimate of the radiation damping $\tau^x_{rad} = 17.5$ ms and the instability threshold current of 151 mA.




Horizontal feedback produces damping rates roughly equal to the growth rates indicating a 6 dB gain margin for gain reduction. At the currents above 900 mA the damping rates do not increase appreciably pointing to the feedback channel saturation. In the tested configuration the horizontal feedback system is not fully resistive and produces a tune shift of 0.0015.

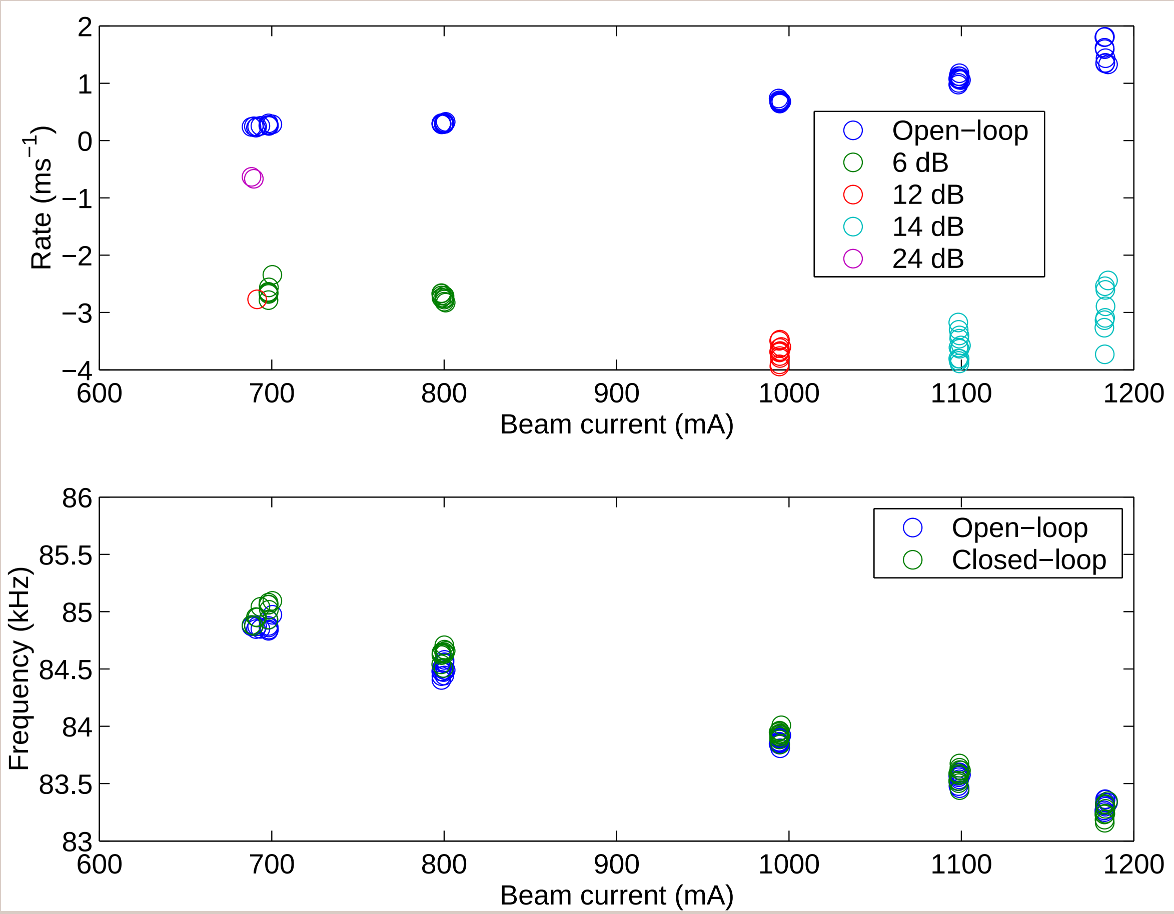
# HER vertical grow/damp measurements

Same eigenmode as in X

Much faster growth rates than in horizontal plane

No tune shift - very good resistive tuning for mode -1.

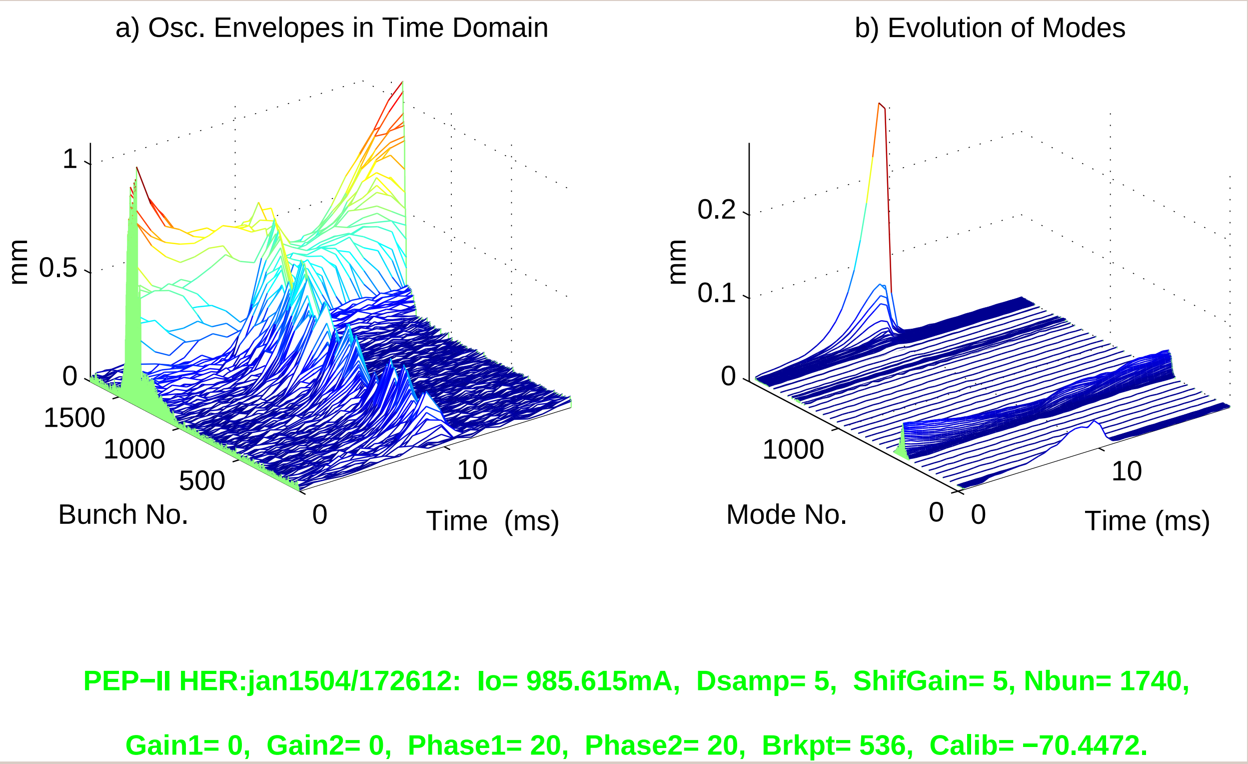
Feedback system was saturated - gain reduction by 6 dB shows no change in feedback damping.




Interesting behavior at the highest beam currents - some bunches in the train broke out in oscillation. Alleviated the problem by lowering the feedback gain, in the end by 18 dB.

# Vertical grow/damp: some bunches unstable

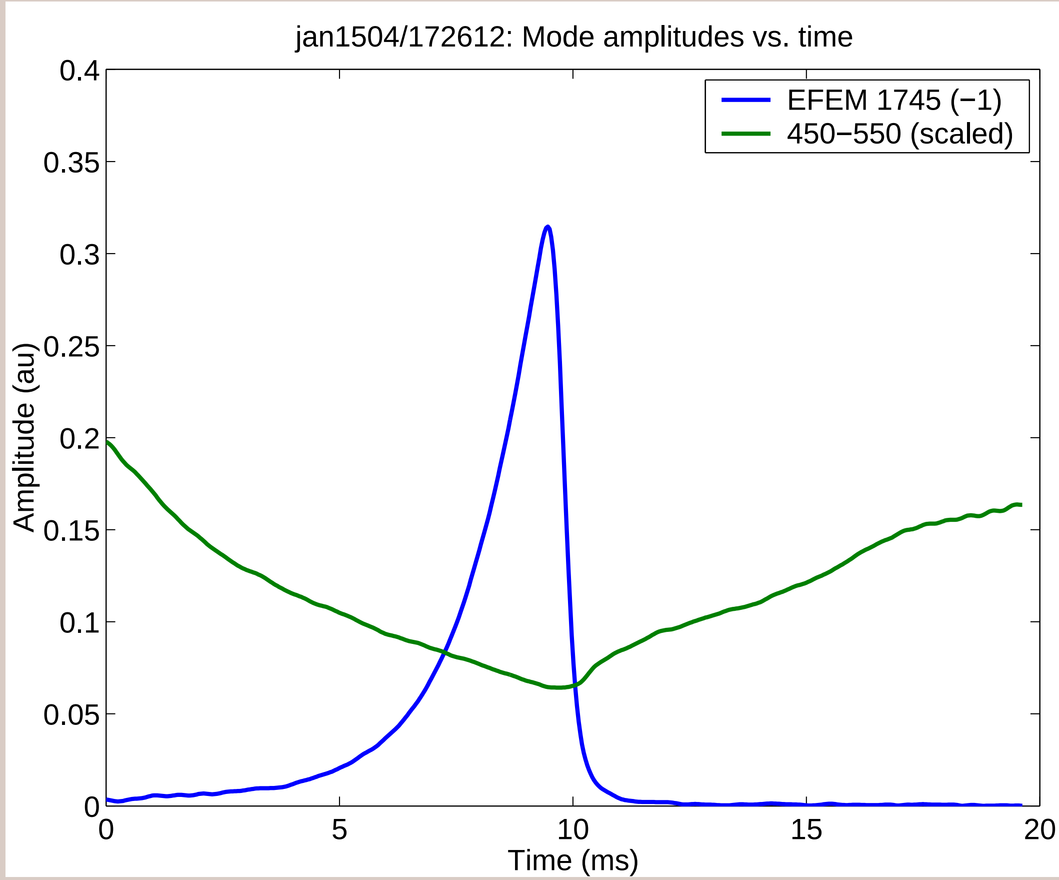
This transient measurement is started with the bunches in the tail oscillating at large amplitudes. When the feedback turns off those bunches damp while the rest of the train grows. After the feedback loop is closed at 10 ms the opposite effect is clearly seen. This indicates that the vertical feedback system has excessive gain and is exciting a subset of bunches (and modes).



# Vertical grow/damp: modal amplitudes vs. time

If we consider the motion in the EFEM basis we see the resistive wall modes growing and damping as expected.

However there is a band of modes around EFEM 500 that has the opposite behavior. While mode -1 has clear exponential growth and damping, modes 450-550 damp in the open-loop configuration. Clearly, the bunches at the tail of the train are oscillating at a higher-order mode frequency.




The bunches are still stable as evidenced by $1 - e^{-\lambda t}$ growth after 10 ms, but are antidamped by the excessive TFB gain and amplify ever present noise excitations. In the PEP-II RF cavity transverse impedance calculations and measurements there are several vertically oriented modes at frequencies that alias to the EFEM range 500-550.

# Transverse stability summary

## HER X

- If the observed feedback saturation is real the horizontal plane runs out of damping between 2 and 3 A
- Growth rates measured in the single ring configuration, better situation in collision
- Technically would expect better damping from the existing transverse feedback systems

## HER-Y

- Nonlinear change in growth rates with current makes predictions difficult
- The feedback system could clearly be retuned for better damping

## LER

- No data, need to make grow/damp measurements

# Resources for longitudinal control

## Low group-delay woofer

- AIP project in progress, no resource problems

## Klystron linearizers

- 4 prototype units in production, expect to install in all LER stations before startup
- Production units will require 6 man-months of hardware engineering, 4 man-months of software development, and 4 months of technician labor.

## Gboard

- As of now hardware development proceeds with minimal resources - three SLAC engineers at roughly 0.25 FTE each, M. Tobiyama (KEK), A. Drago (LNF).
- Funded by ARDA and US-Japan collaboration
- Current projections: start layout in January, expect prototype units in April.
- The project is severely manpower limited - need both hardware and software resources; help to date from KEK with hardware and LNF-INFN with software development.

# Resources for longitudinal control (continued)

## Second generation front and back-end electronics

- I&Q processing, expanded diagnostics.
- Design and build after the Gboard is ready

## “Frascati”-style kickers

- Complete and installed
- Improved thermal management at high currents
- Higher shunt impedance only useful with the low group-delay channel (Gboard)

## Comb-2

- In progress, funded and staffed
- Asymmetric comb filters and equalizer for improved impedance control

## Digital RFP

- Research-level project now, aimed at eliminating drifts and calibration problems

# Resources for transverse control

## 2-tap filter and delay line

- Funded, on-track for February delivery
- Should improve orbit and gap transient rejection

## Transverse kickers

- Improved kickers installed in the LER
- Will continue transverse kicker modeling and design efforts

## 3rd generation processing

- Transition to Gboard when ready to take advantage of common hardware, software, and beam diagnostics in all planes
- I&Q processing an option