Observations of single bunch collective effects in the Advanced Light Source

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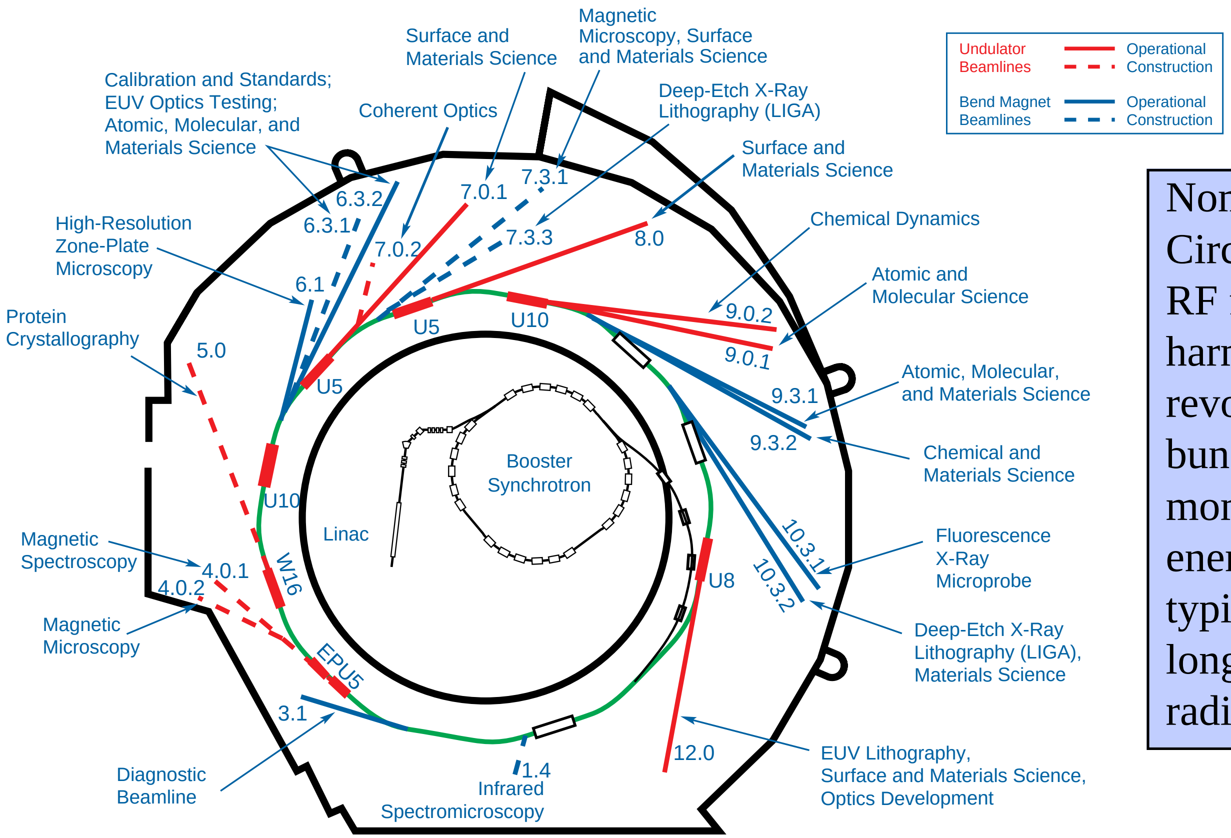
Overview

- Overview
  - the Advanced Light Source
  - applications of high current/bunch
  - ALS vacuum chamber
- Longitudinal observations
  - bunch length, energy spread, synchronous phase shift vs. I
  - BPM spectrum vs. I
  - simple impedance model
- Transverse observations
  - tune shift, HT damping vs. I
  - MCI thresholds
  - control of MCI with feedback
- Conclusions

The Advanced Light Source



Nominal Energy	1.5-1.9 GeV
Circumference	196.8 m
RF frequency	500 MHz
harmonic number	328
revolution frequency	1.52 MHz
bunch current	1-2 mA
mom. compaction	1.6e-3
energy spread	7e-4
typical bunch length	4.5 mm
long. damping time	13 msec
radiation loss/turn	90 kV

1 mA=2/3 nC=4.16e9 electrons

Applications of high current/bunch at ALS

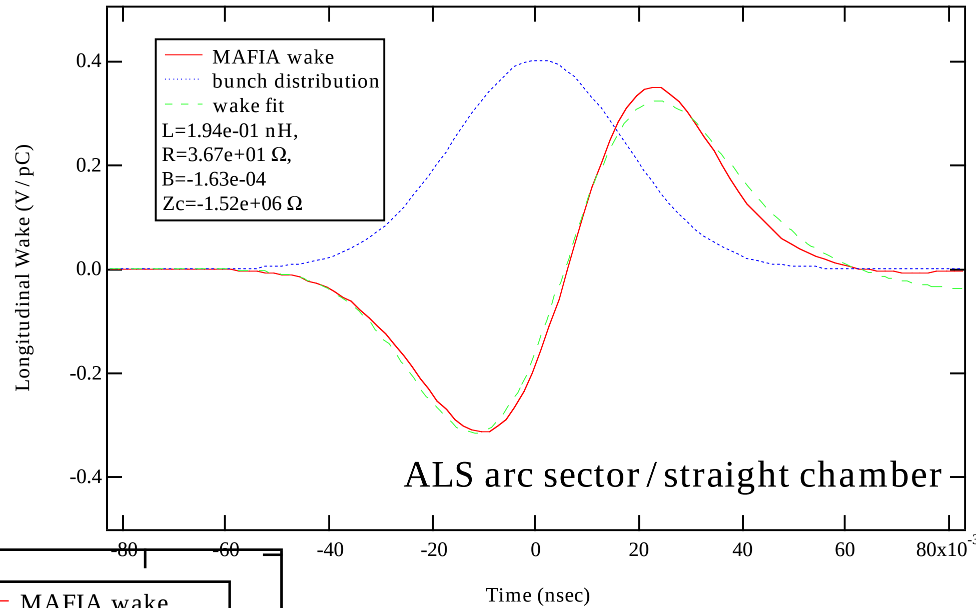
- Femtosecond slicing, Bragg switching
  - requires highest peak current possible in ~100 fsec longitudinal beam section
  - sensitive to bunch lengthening/energy widening
- Ion-electron Time-of-flight detectors
  - require large current/bunch separated by at least 300 nsec
  - somewhat sensitive to energy widening but not bunch length

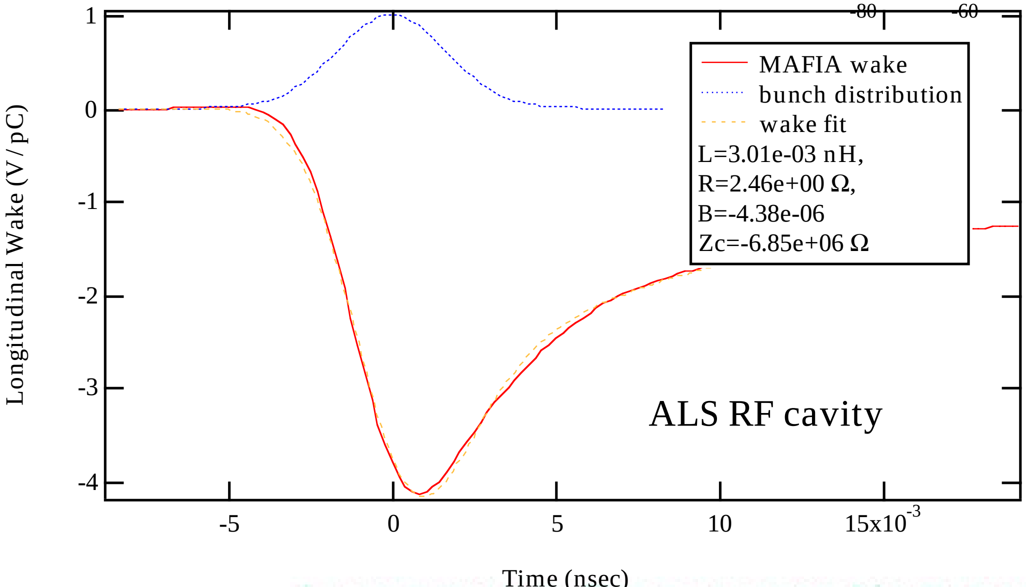
ALS Vacuum Chamber

- 200 m circumference
- 12 sectors: 1 straight for injection, 1 for RF/FB kickers, 1 for pinger/harmonic cavs
- vacuum chamber w/antechamber design
- 2 main RF cavities (500 MHz), 5 harmonic cavities (1.5 GHz)
- 48 bellows with flexbend shields
- 4 LFB "Lambertson" style kickers, 2 transverse stripline kickers
- 1 DCCT
- 96 arc sector BPMs, 24 insertion device BPMs
- 4 small gap insertion device chambers (8-10 mm full height) w/tapers to 42 mm arc sector chamber.

ALS Wakes

Use calculated MAFIA wakes and fit with Zotter/Bane/Heifets impedance





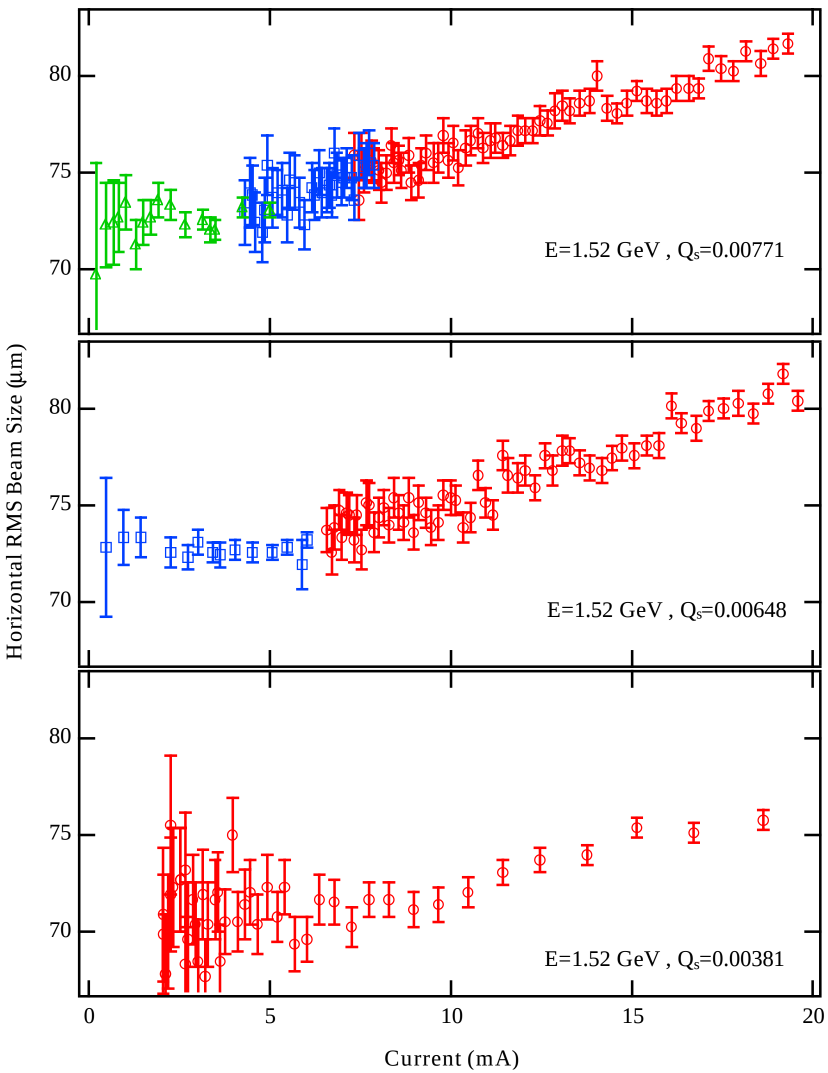
Energy Spread

Technique: measure transverse beam size at a point of dispersion. Zero current beam size assumed to be due to nominal emittance and energy spread.

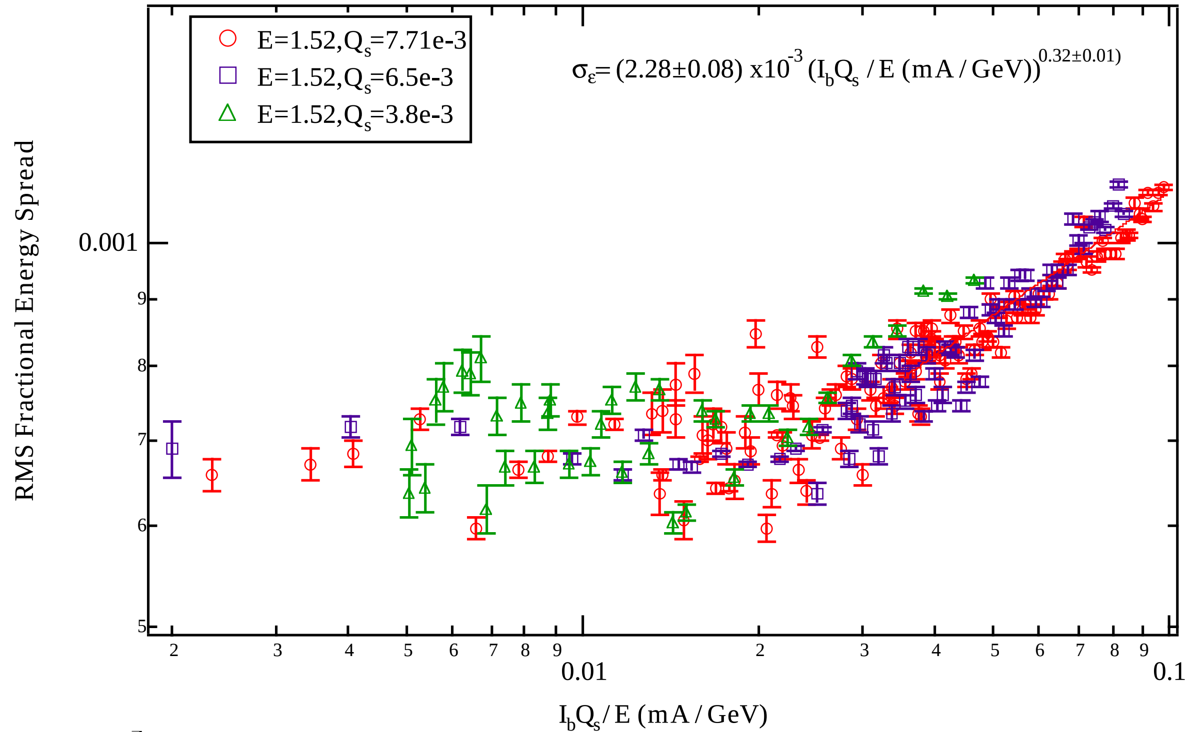
$$\sigma_\varepsilon^2 = \frac{1}{\eta_x^2}\left(\sigma_x^2 - \sigma_{x0}^2 + (\eta_x \sigma_{\varepsilon 0})^2\right)$$

Measured at 1.5 GeV at 3 nominal RMS bunch lengths: 4.3, 5.1, 8.7 mm

etax=4.3 cm
etay=-1.3 cm



Energy spread summary



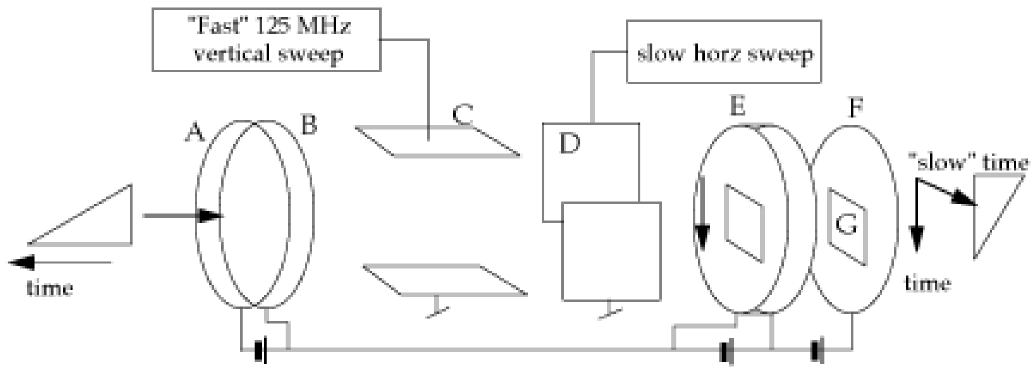
Plot data at 1.5 GeV using Chao-Boussard scaling

$$\sigma_\varepsilon^3 = \frac{1}{\sqrt{2\pi}\alpha^2}\left(\frac{I_b Q_s}{(E/e)}\right)\left[\left|\frac{Z_{//}}{n}\right| + \mathrm{Im}\frac{Z_{//}}{n}\right]$$

$Z / n = 0.08\ \Omega$

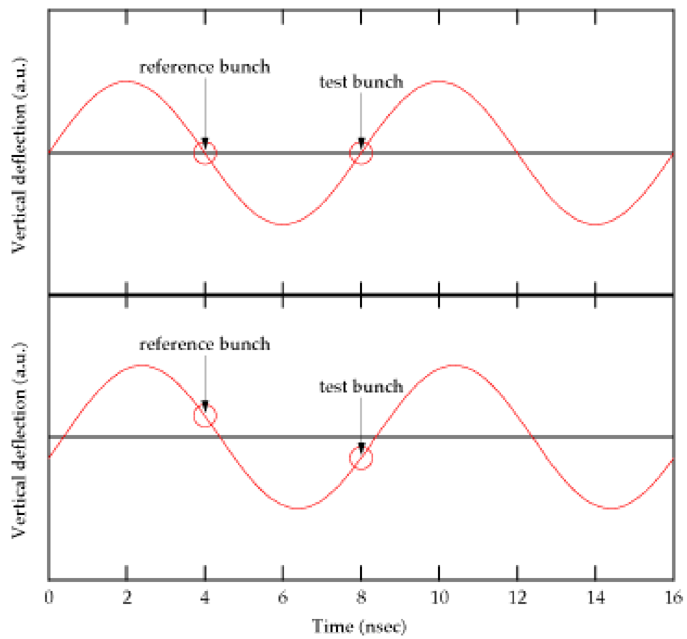
At 1.9 GeV, no sign of energy widening up to 20 mA

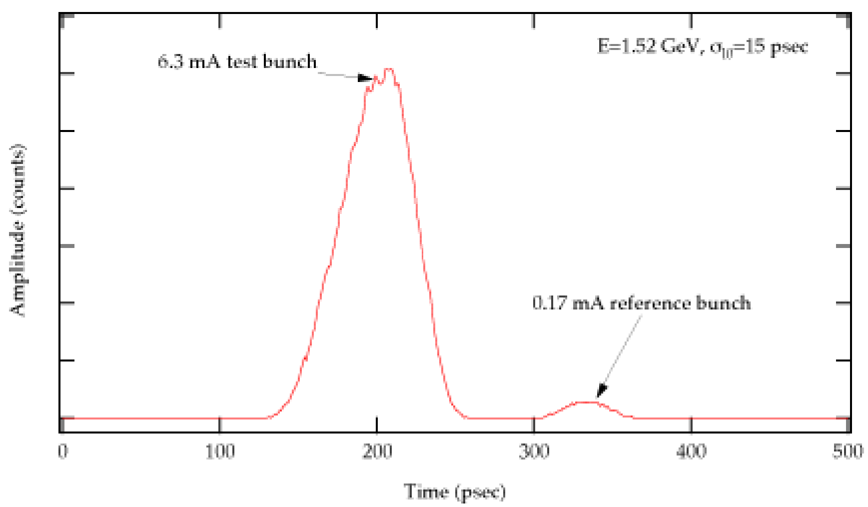
Dual-Scan Streak Camera



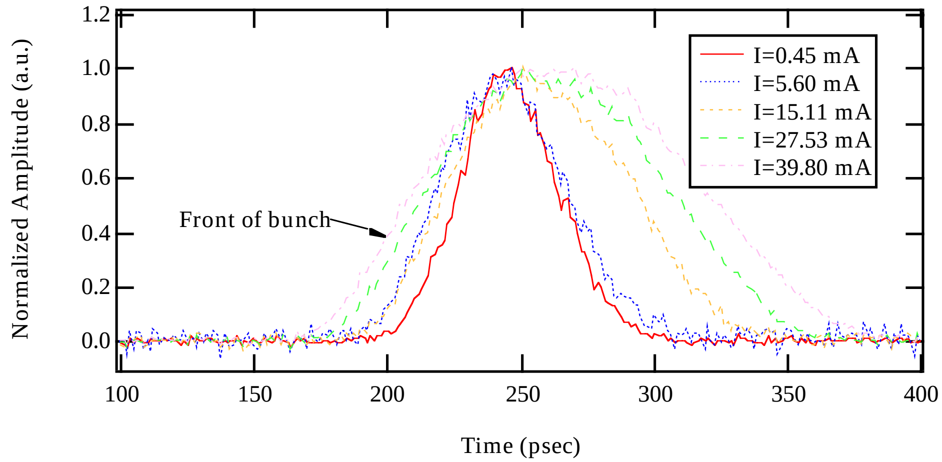
All bunch length measurements done using Hamamatsu C5680 Streak camera w/ dual synchroscan

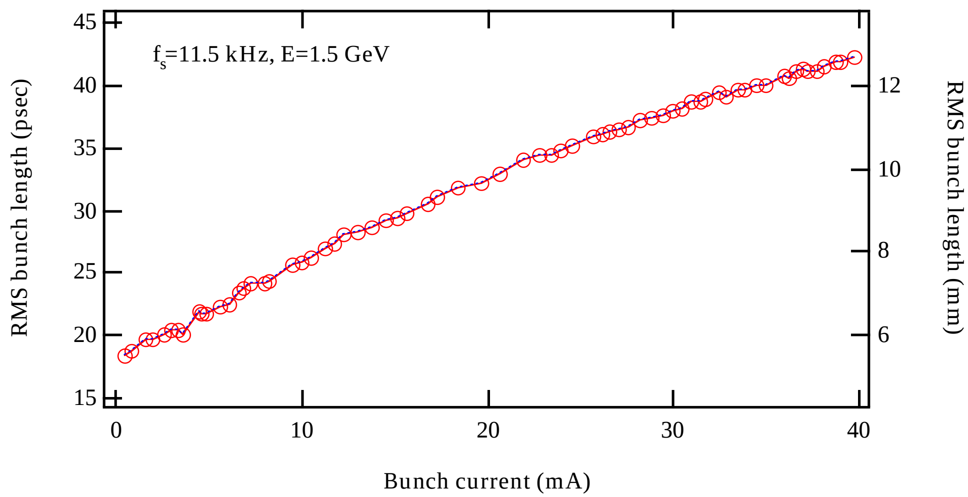
Phase shift measurements done using small test bunch





Bunch length vs. current





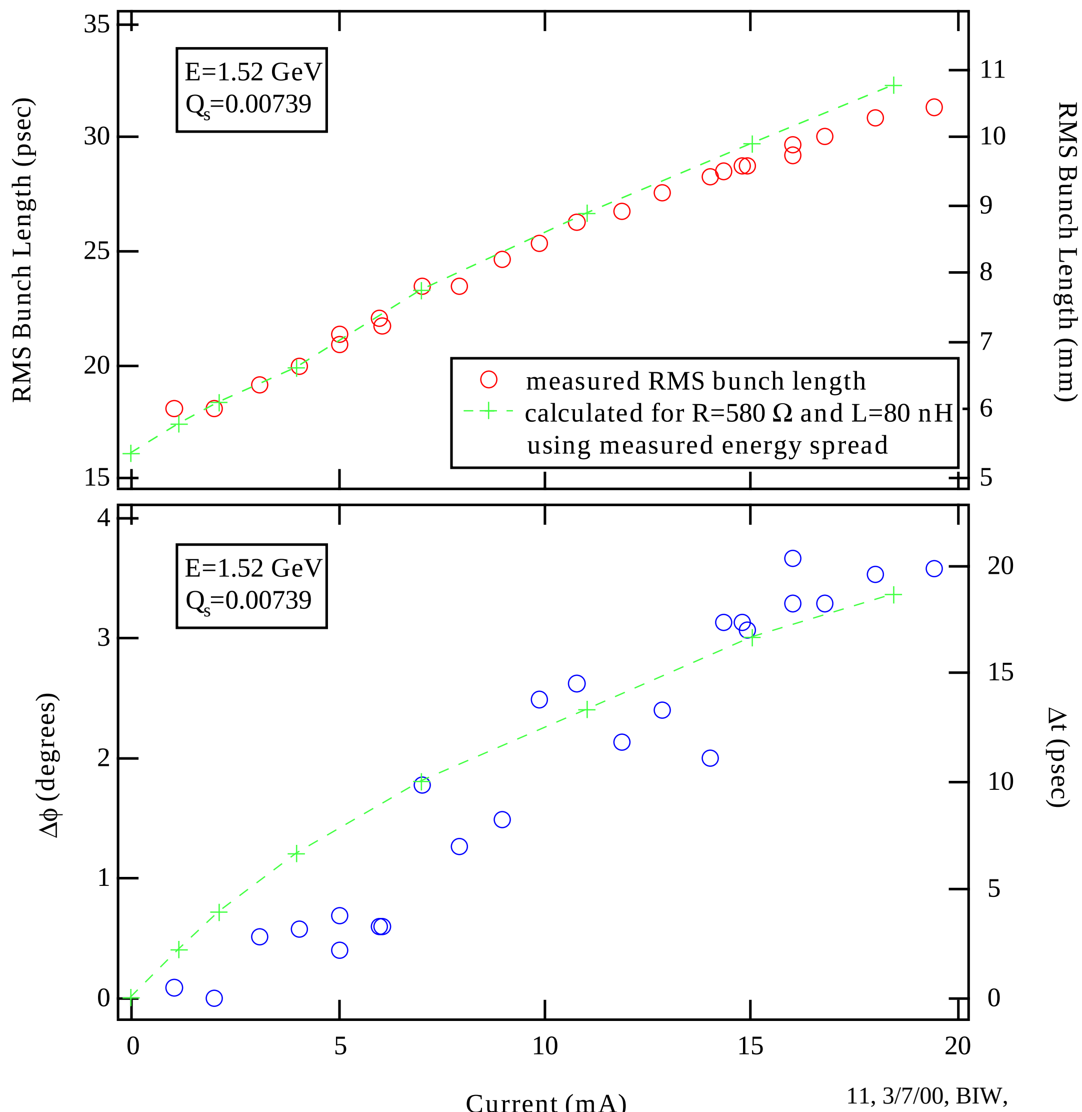
Bunch length and synchronous phase shift

Measured results fit with Haissinski equation using simple RL model.

Measured energy spread used in Haissinski.

Results consistent with R= 580 Ω, L=80 nH.

Data made at longer bunch shows worse agreement, probably due to coherent quadrupole instability at higher currents.



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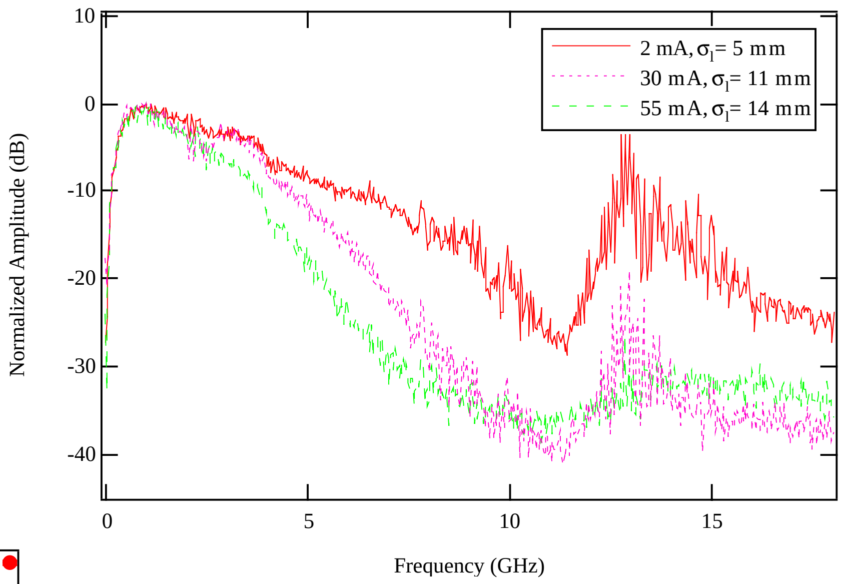
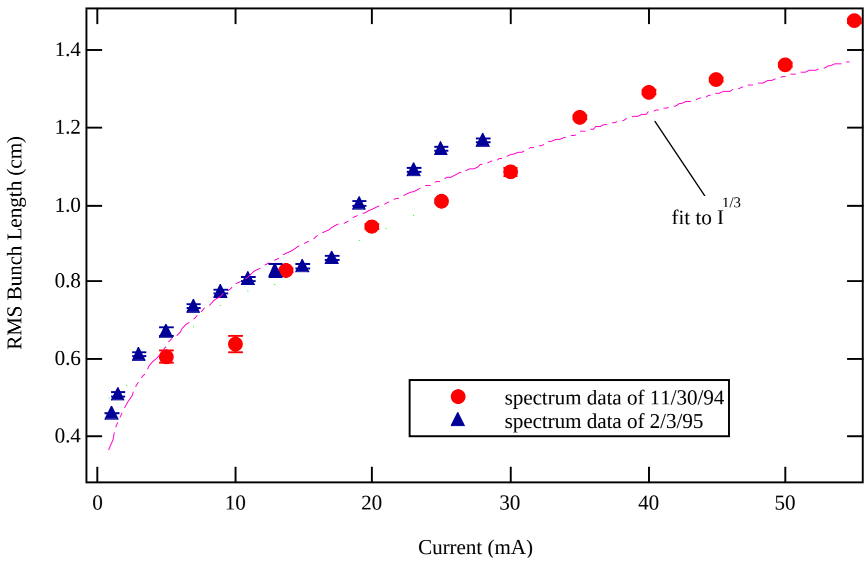
Broadband BPM spectra

Prior to buying a streak camera, we used a broadband BPM signal to measure bunch length.

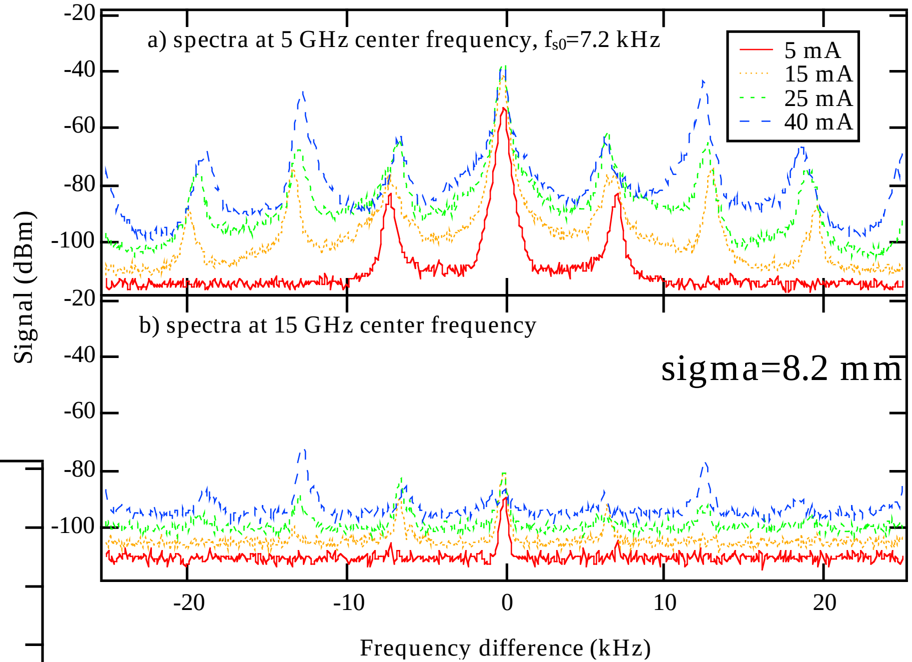


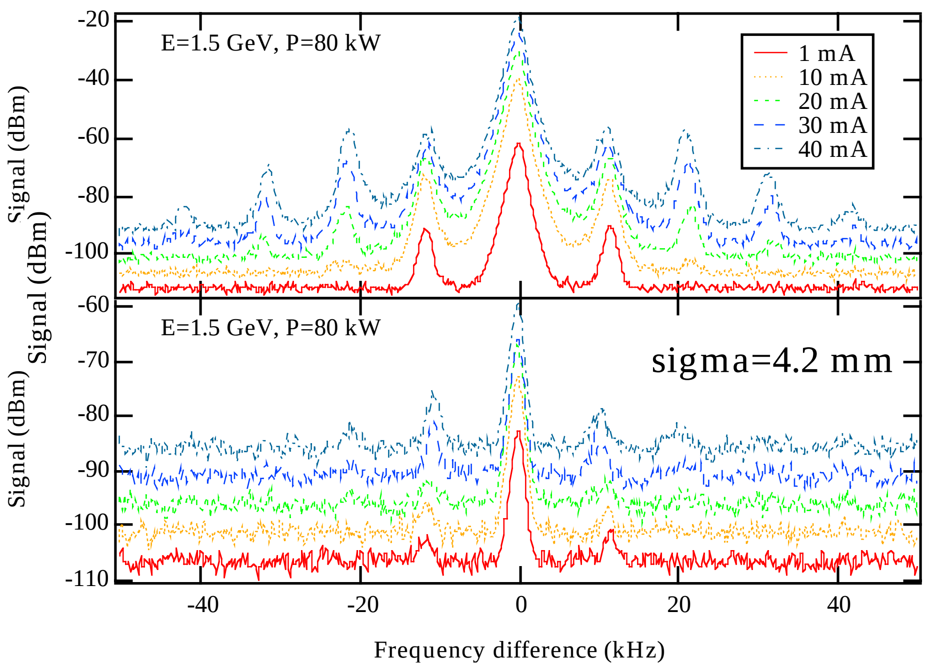


bunch length follows I** 1/3 law up to bunch currents of 60 mA

Sideband spectra

We also measured synchrotron sideband amplitudes at various frequencies. The dipole motion at low current is driven by RF phase noise.





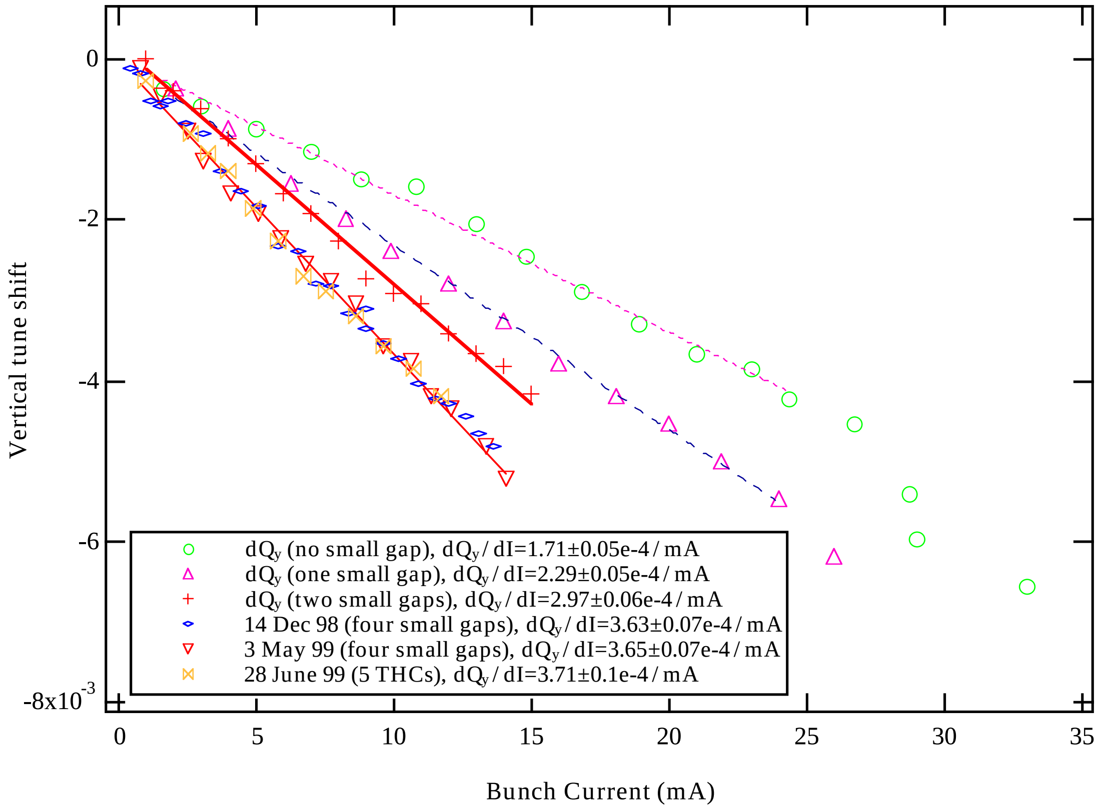
The spectra at longer bunch length shows a clear coherent quadrupole motion. This is also evident on streak camera data. The short bunch data does not show any clear modes.

Vertical tune shift vs. I

Measured vertical tune shift vs bunch current since beginning of ALS operations

$$\frac{dQ}{dI} = \frac{R}{4\sqrt{\pi}(E/e)\sigma_l}\beta Z_{eff}$$

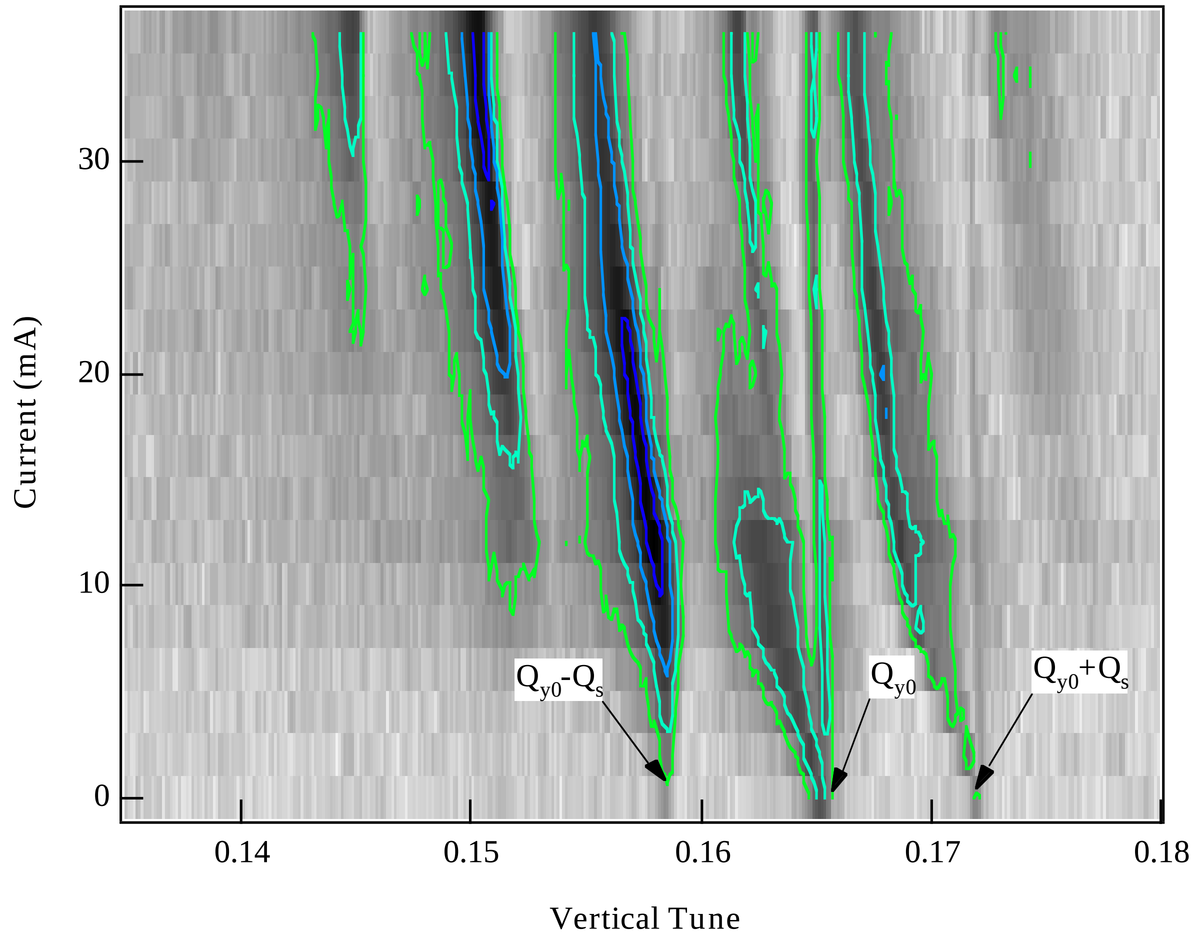
Zeff,vert=250 kΩ



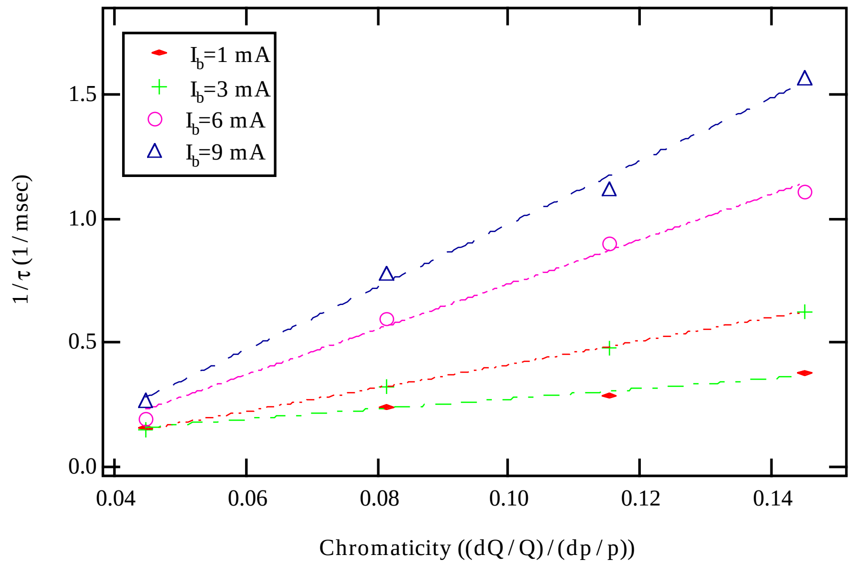
Tune shift vs. I

Measured vertical tune spectum with swept frequency excitation. Large currents reached using large vertical X>5.

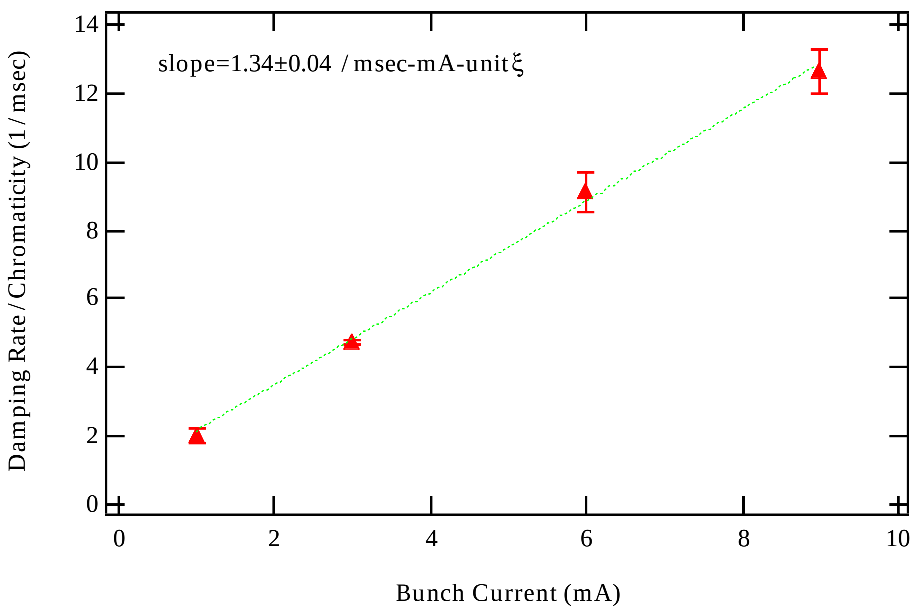
Note persistence of original tune line.



Head-tail damping rate vs. I



Measure vertical and horizontal damping rates vs. X and I.

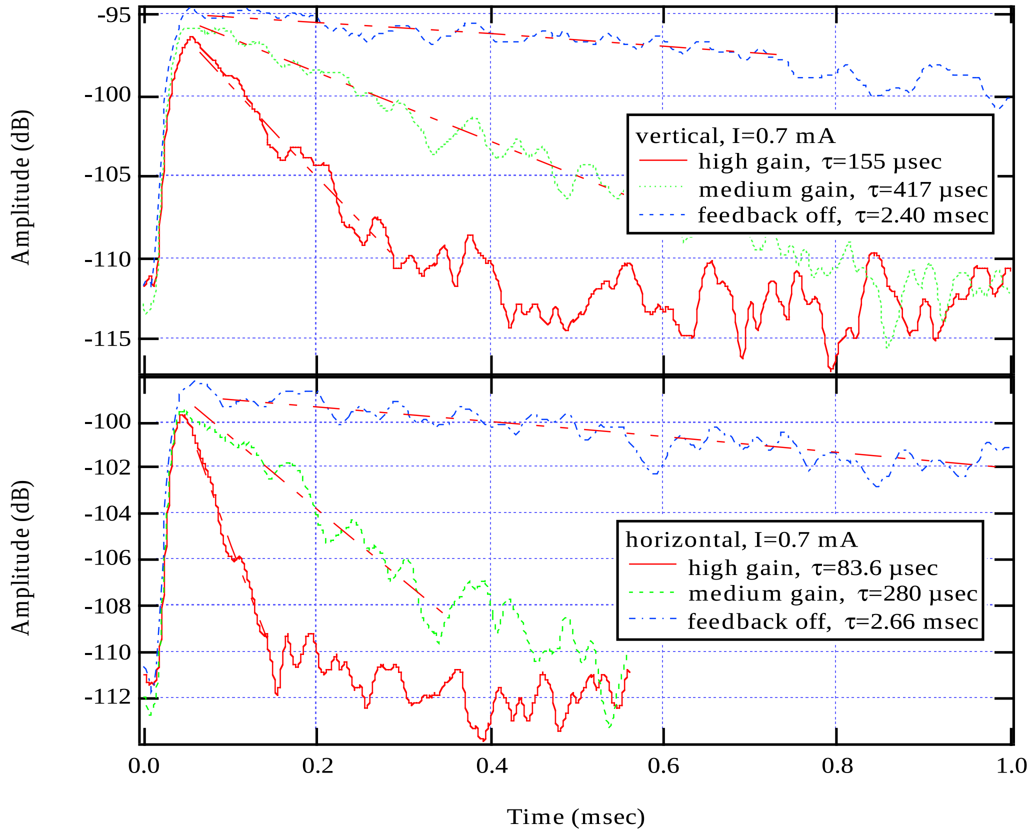


Mode-coupling threshold

- Vertical mode-coupling hreshold has dropped by a factor of 2 with installation of 5 small gap vacuum chambers
- Main current-limiting mechanism due to small vertical physical aperture.
- Unclear whether generated by resistive wall impedance or tapers.
- Threshold depends on vertical orbit through small gap chamber
- Threshold *decreases* with vertical X up to around 5 when it vanishes. Maximum current injection limited to around 35-40 mA with very short lifetime.
- Horizontal threshold appears to be around 25 mA.
- Displays hysteretic behavior.

Feedback control of TMCI

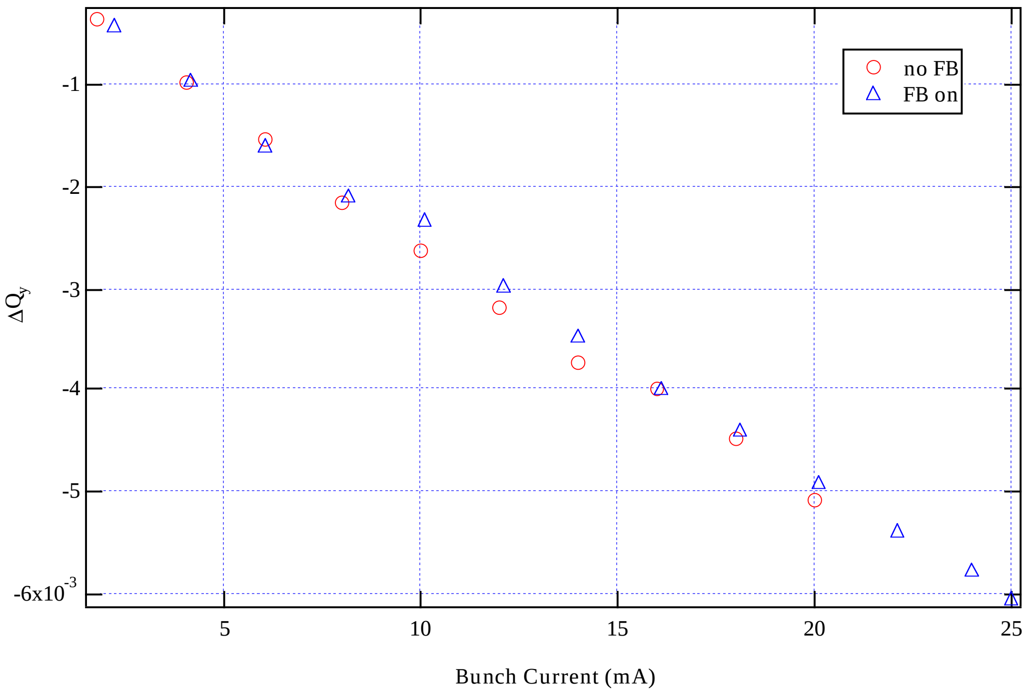
- Reconfigured existing multibunch transverse FB system to work for high current single bunch.
- FB has arbitrary phase adjustment using 2 PUs about 60 degrees apart in betatron phase.
- Sensitive buttons and electronics allow for high gain.
- both vertical and horizontal FB used to control TMCI.



Measured h+v damping rates for various gain settings

FB control of TMCI (cont.)

Empirical adjustment of the FB phase gives highest bunch currents with FB in resistive mode. Bunch currents of 37 mA achieved with vert.+horz chromaticities of ~0.5. This gives the maximum dynamic aperture and the longest lifetime.



Interesting questions:
-what is the effect of damping of the m=0 mode on the coupling?
-How much of a perturbation is req'd to start the growth?

Tune shift vs current with and without FB. Highest currents operated with FB in resistive mode

Summary

- ALS bunch lengthening and energy spread characterized at 1.5 GeV.
- Energy spread gives $|Z/n|=0.08\ \Omega$
- Simple analysis shows bunch lengthening consistent with L=80 nH, R=580 Ω.
- Sophisticated analysis may start someday...
- Transverse impedance dominated by small gap chambers for insertion devices.
- Transverse mode coupling instability controlled using FB in resistive mode