(Re)Discovery of the Sawtooth Bunch Length Instability in the SLC Damping Rings

- A Historical Overview

Patrick Krejcik

SLAC Accelerator Department

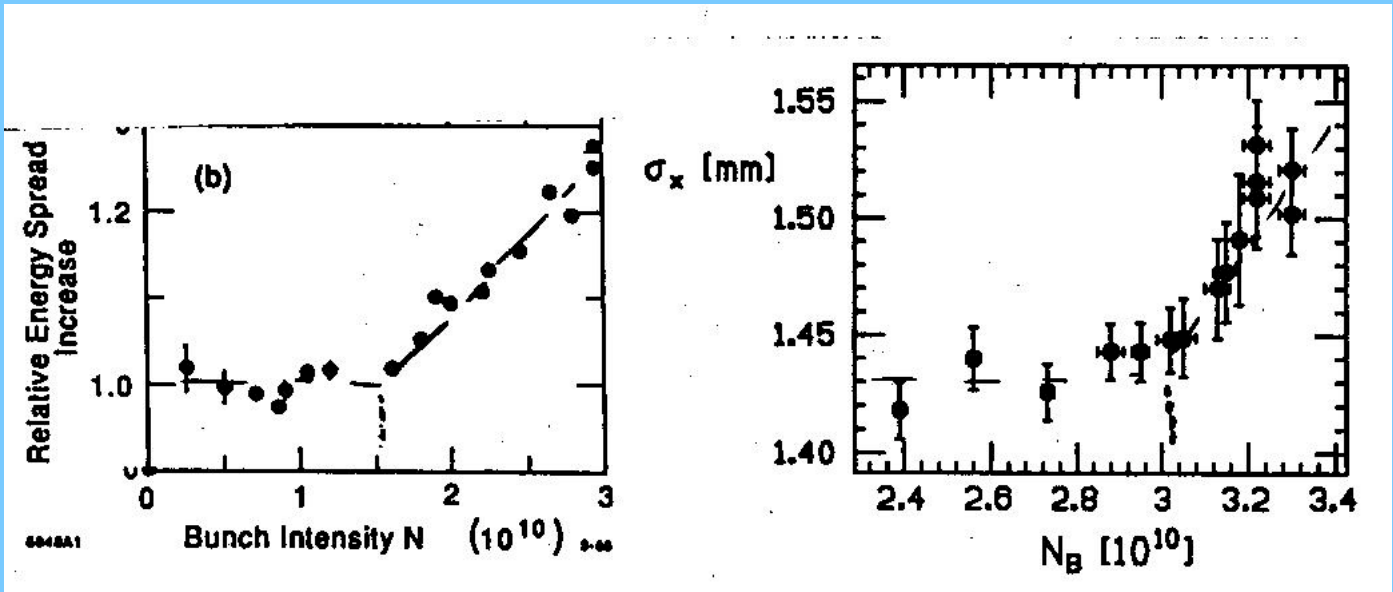
Workshop on Broadband Impedance Measurements and Modeling, Feb.29, 2000.

Diagnostic Tools

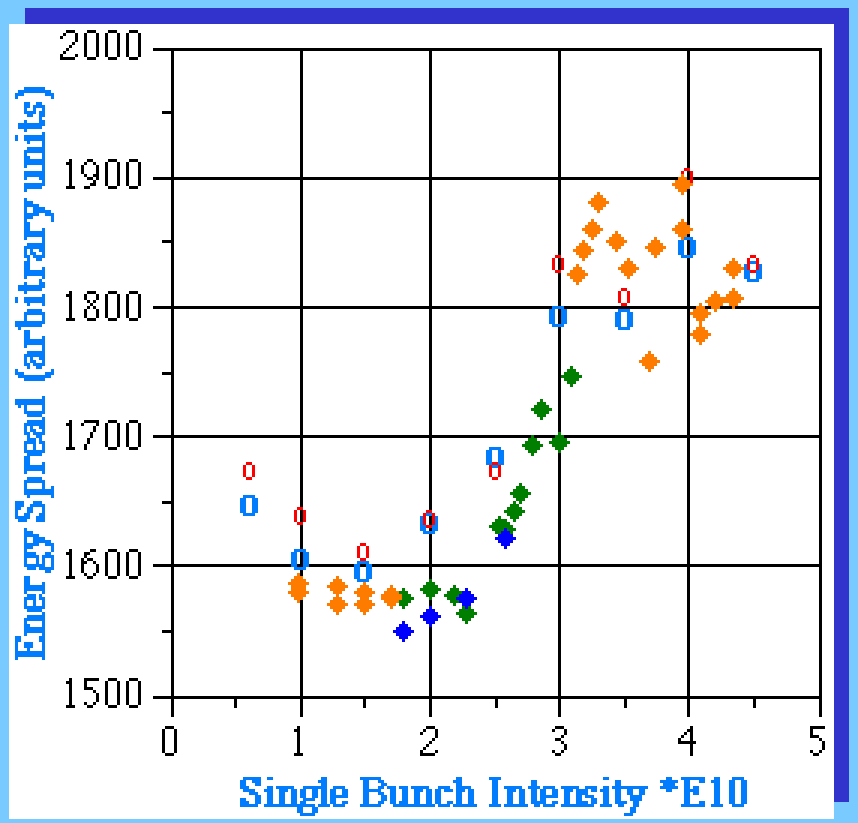
- **Orbit of extracted beam**
  - **flier pulses**
  - **linac Δ energy => ring Δ extraction phase => Δ I_{peak} => $\Delta\sigma_z$**
- **Steady state measurements**
  - **Energy spread of extracted beam**
    - **beam size at high dispersion location, av. of many pulses**
  - **Bunch length of extracted beam**
    - **from energy spread after bunch rotation**
  - **Streak camera bunch length measurement**
    - **snapshot at single instant during the store**

Energy spread of extracted beam versus Intensity

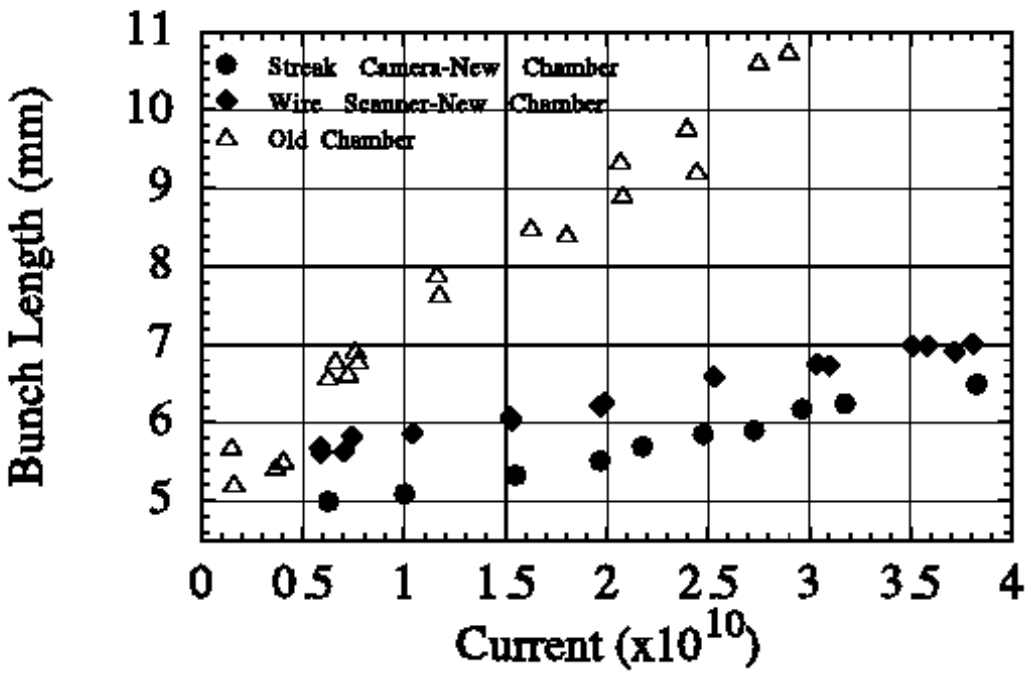
Original unsleeved chamber (left) **Old sleeved chamber (right)**



Extracted Beam Energy Spread vs. Intensity for the low impedance chamber



Bunch length vs. intensity for the old and new vacuum chambers

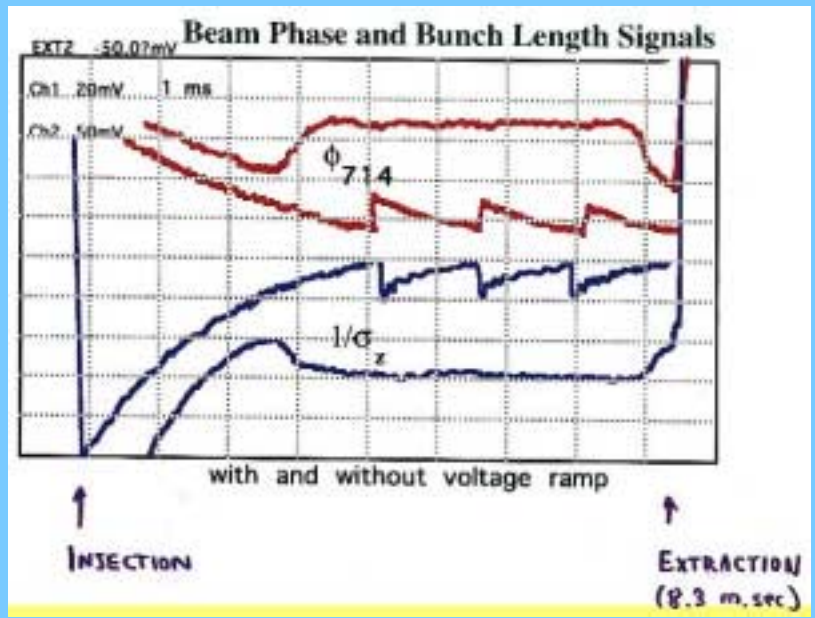


Diagnostic tools
- dynamic observations

- Beam phase
  - oscilloscope display of evolution during beam store
  - measured wrt to cavity RF not master oscillator
- Bunch peak current monitor
  - bpm button peak amplitude
  - oscilloscope display of evolution during beam store
- Spectrum analyzer
  - limited bandwidth of bpm cables

Sawtooth signals

- Beam phase with and without RF voltage ramp.
- Peak current (bunch length)$^{-1}$ signal with and without voltage ramp.

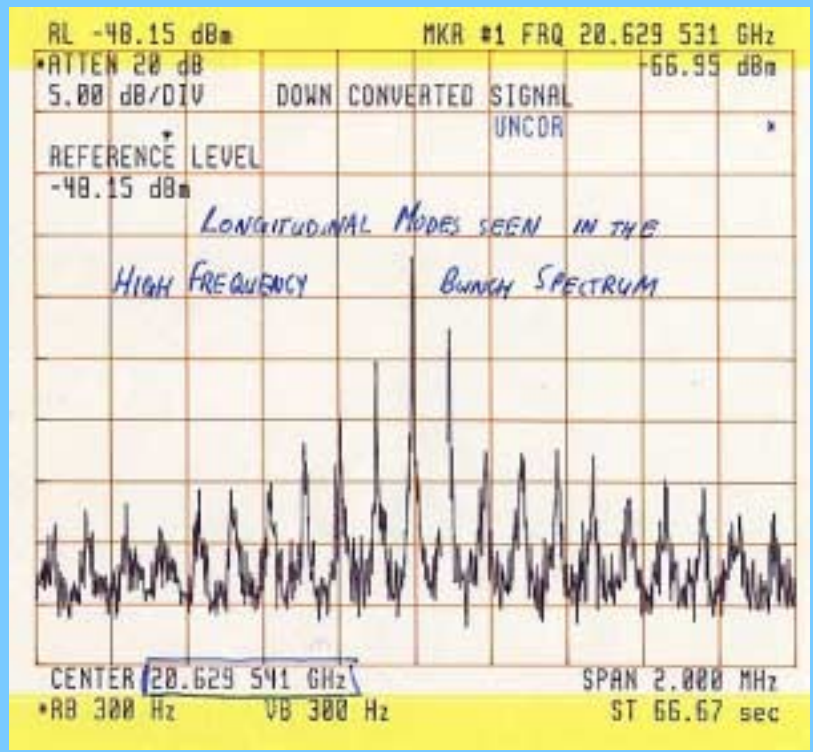


Diagnostic tools
- swept spectrum analyzer

- New high bw cable signal path and 27 GHz front end
  - spectrum dominated by injection transients
    - observe many higher order sidebands
- Observe time evolution at one sideband frequency
  - spectrum analyzer set to zero span and triggered at injection

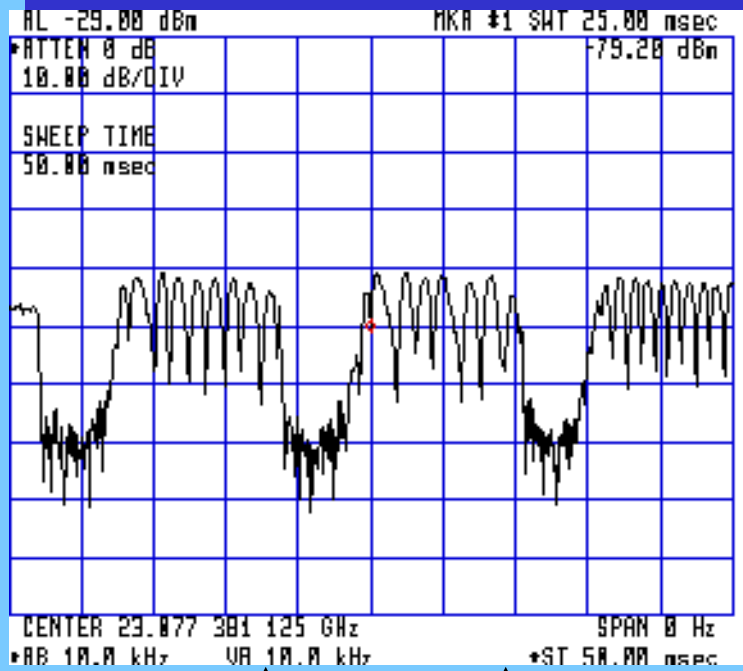
Swept spectrum above 20 GHz

- Swept spectrum at 21 GHz detects many higher-order sidebands
- dominated by injection transients

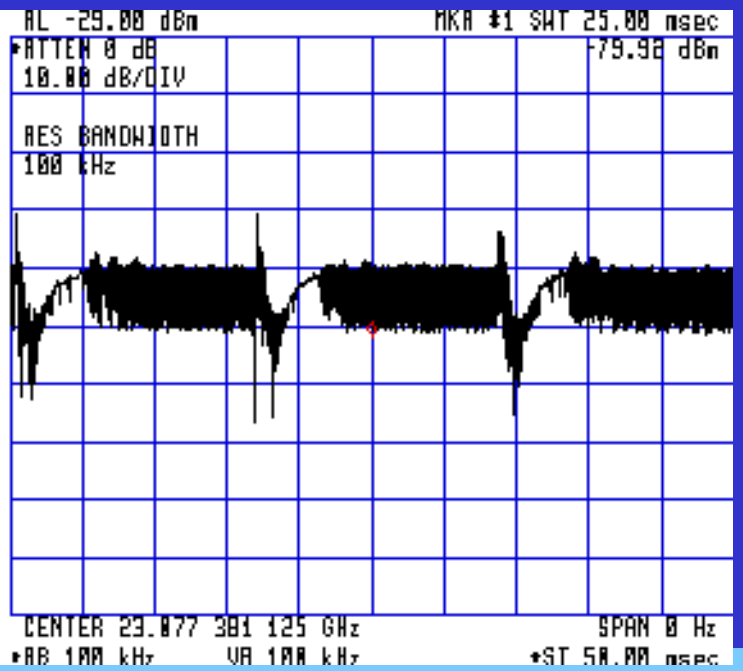


Time evolution during the store of a 2 ν_s sideband at 23 GHz

Sawtooth bursting mode



Continuous instability



Injection

Extraction

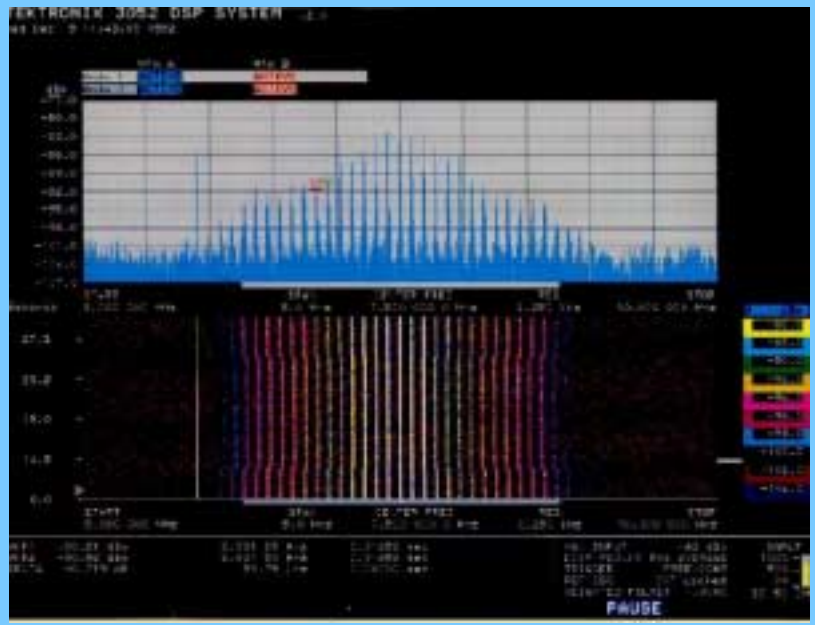
Diagnostic tools
- gated DSP

- IF output from previous spectrum analyzer down mixed to 7.5 MHz
- Tektronix 3052
- Allows FFT of gated, ~ 1ms duration sample, triggered e.g. mid-store
  - definitive identification of $3\nu_s$ sideband signature

- Dependence on charge per bunch
  - disable 120 Hz extraction
  - intensity of stored beam decays over 10 minutes
  - use DSP waterfall display
  - confirmation of $3\nu_s$ threshold
    - » $2\nu_s$ evolution
    - » mode jumps!

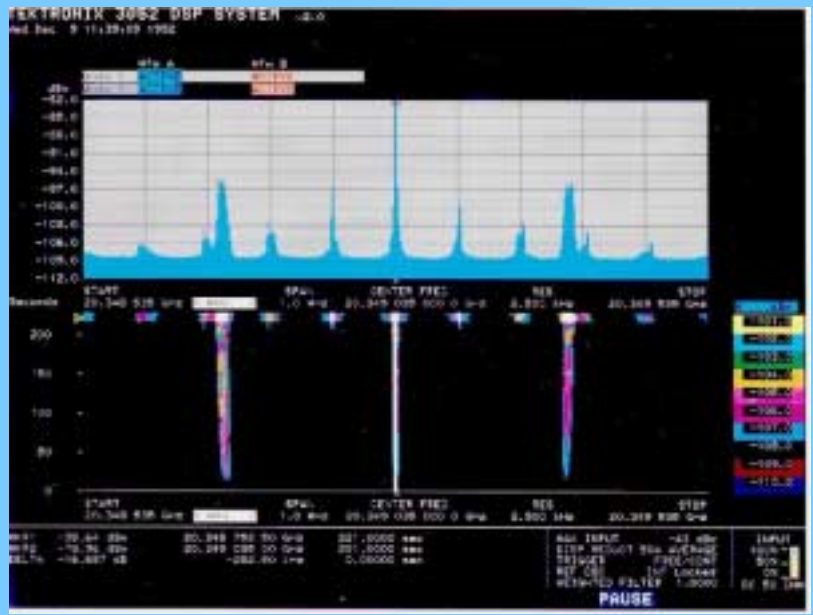
Bunch spectrum centered at 26 GHz

- Injection transients generate many higher order synchrotron sidebands



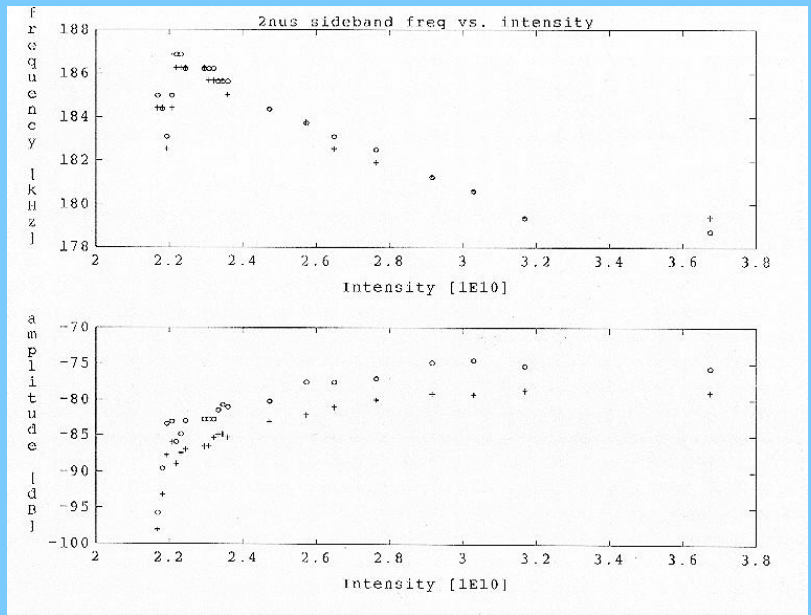
DSP spectrum during instability

- Signal downmixed from 20 GHz, analyzed on DSP
- Instability signal close to 3 ν_s sideband injection transient (top)
- When beam is stored only 3 ν_s signal remains vs. time until intensity drops below threshold (lower)
- Example shown is the “old” high impedance chamber with shielded bellows



Dependence on Intensity

- The 2 ν_s sideband frequency and amplitude for the new low impedance chamber are plotted vs. single bunch intensity



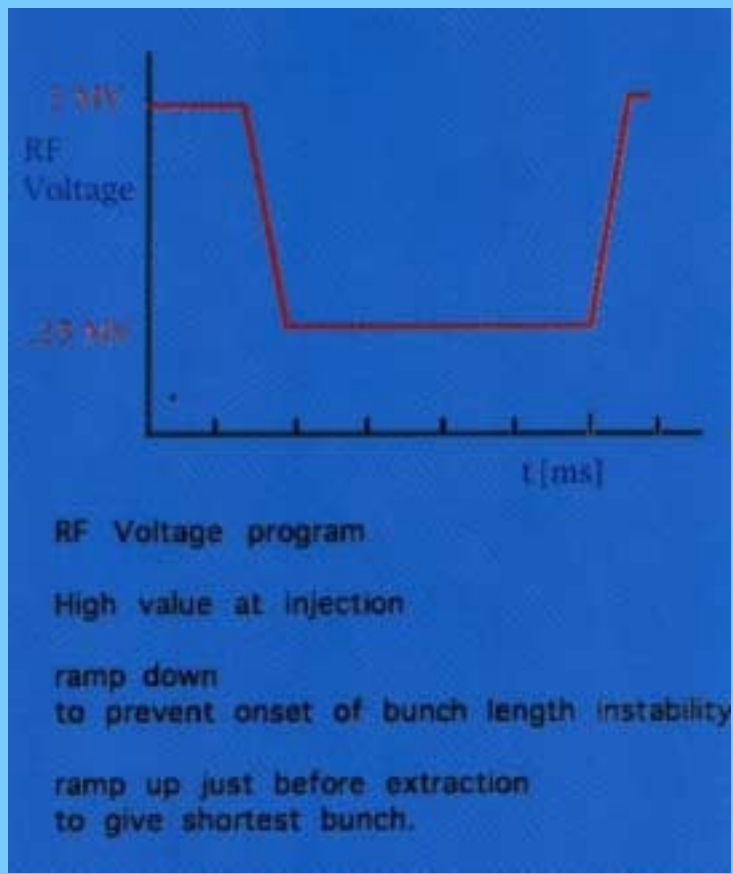
Dependence on RF cavity voltage

$\sigma_z \sim V_{rf}^{-1/2}$

- lowering V_{rf} raises instability threshold
- limited by Robinson beam loading instability
  - when $V_{Klys} < V_{Beam}$
  - ameliorated with direct RF feedback
- Implementation of voltage ramp
  - raised threshold 10%, $3*10^{10}$ to $3.3* 10^{10}$
    - not a permanent fix
    - longer bunch gives undesirable losses in RTL compressor
  - enriched spectral behavior!

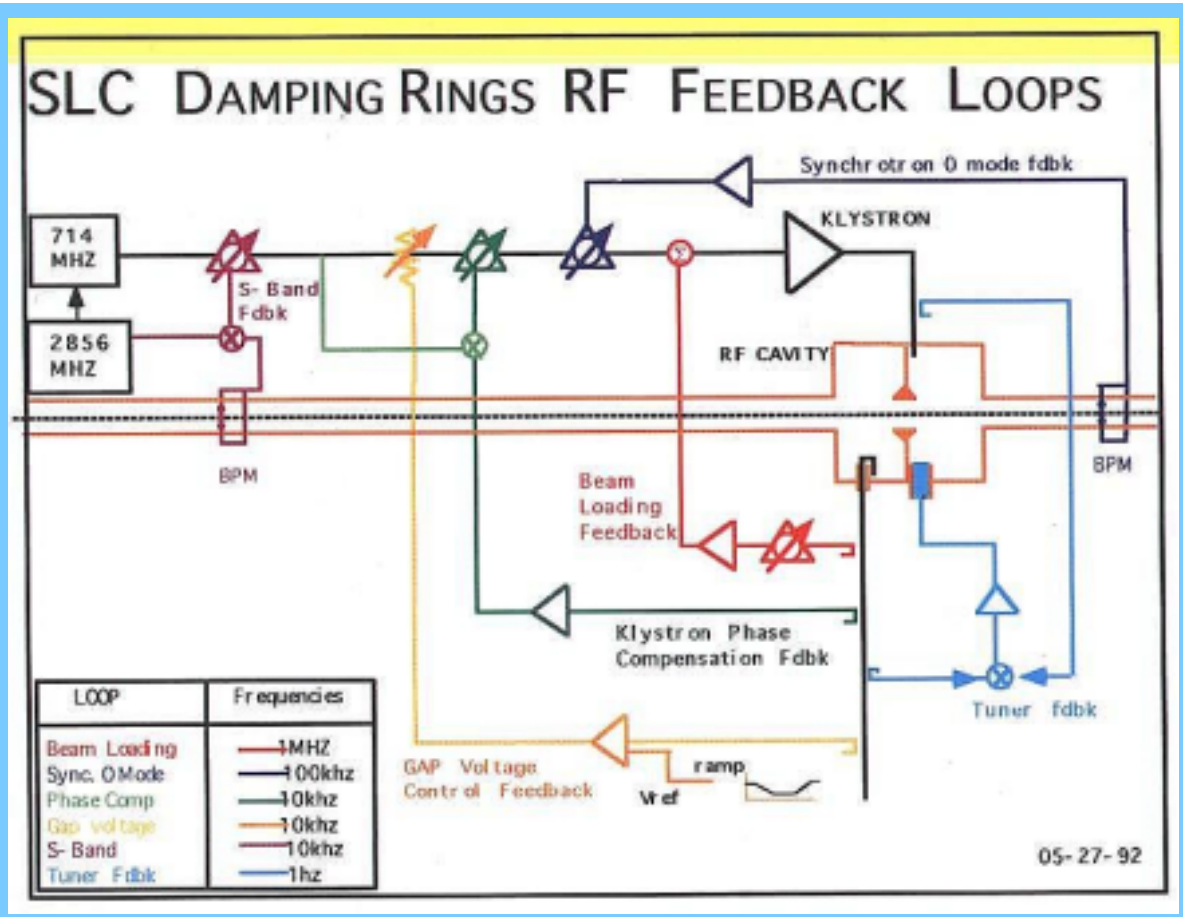
RF Voltage Ramp

- RF amplitude ramped down shortly after injection.
- Bunch lengthens before reaching instability threshold
- Ramp up prior to extraction before beam goes unstable



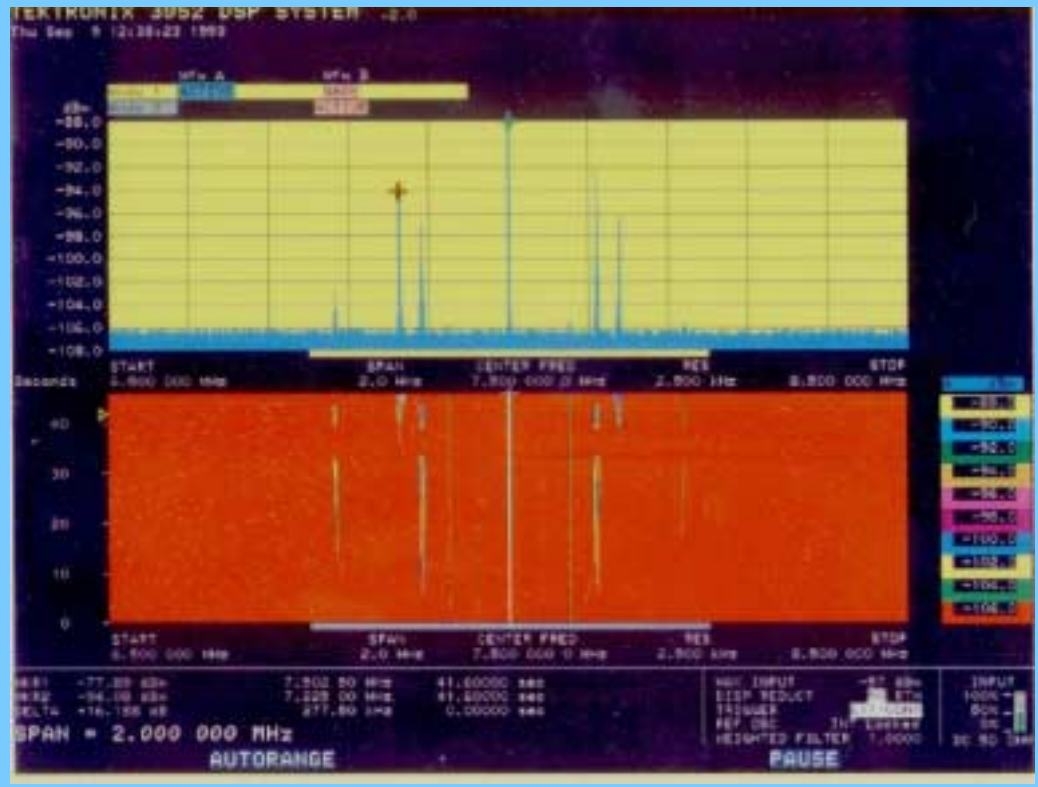
RF feedback loops

Direct RF feedback loop
allows higher beam loading at reduced RF amplitude



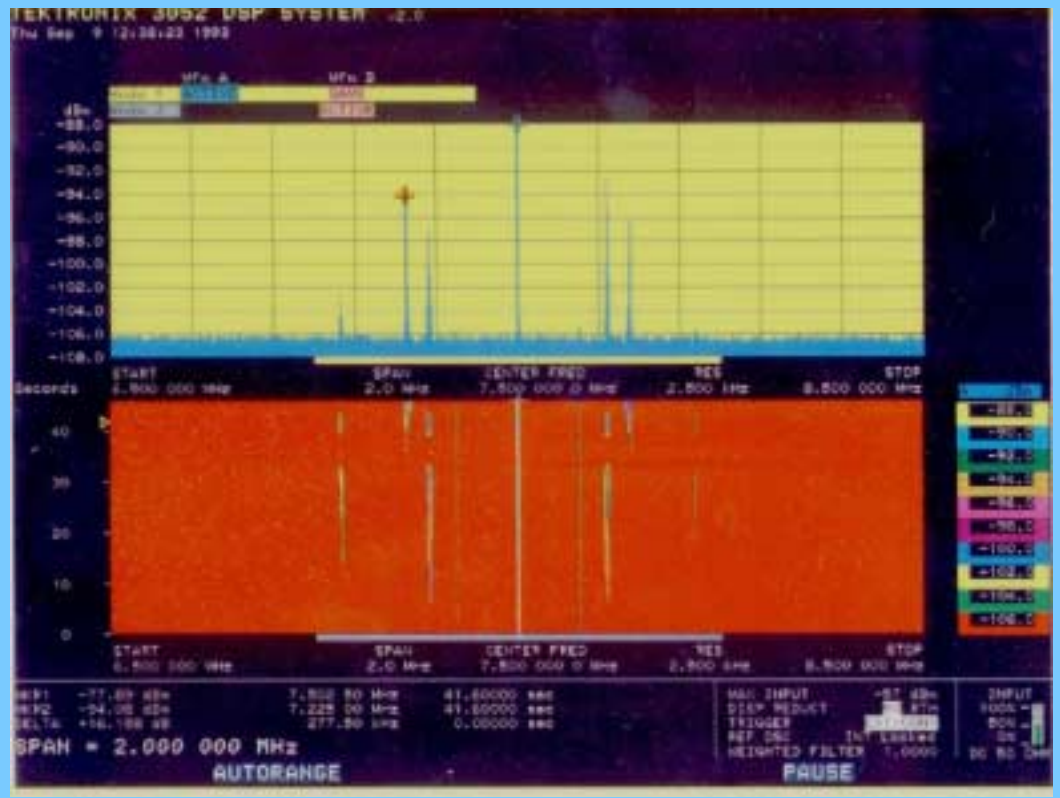
Instability modes vs. Intensity

- 6 ν_s, 3 ν_s and 1 ν_s sidebands appearing at different intensities
- for a RF voltage of 680 kV



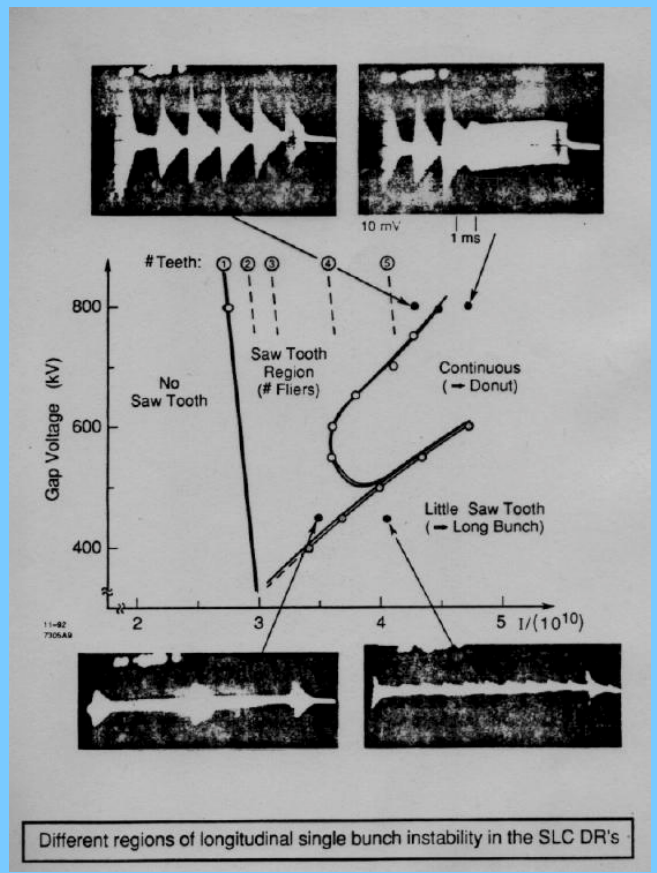
Instability modes at lower RF Voltage

- 6 ν_s, 4 ν_s and 3 ν_s sidebands appearing at different intensities
- for a RF voltage of 525 kV



Instability Regions

- Different regimes of sawtooth instability:
- large, small or continuous
- dependent on RF voltage and intensity (T. Limberg)



Different regions of longitudinal single bunch instability in the SLC DR's

Rediscovery?

- Similar plot of instability regions for SPEAR, from P.B. Wilson, 1975