Electron Cloud Instability Measurements at CESR-TA

October 21, 2010

M. Billing

Participants

- Instability Measurements
  - M. Billing, G. Dugan*, R. Meller, M. Palmer, G. Ramirez, J. Sikora, K. Sonnad, H. Williams, CLASSE, Ithaca, NY
  - R. L. Holtzapple, California Polytechnic State University, San Luis Obispo, CA
- X-ray Beam Size Measurements
  - J. Alexander, M. Cunningham, N. Eggert, W. Hopkins, B. Kreis, D. Peterson, CLASSE, Ithaca, NY
  - J. Flanagan*, KEK, Japan

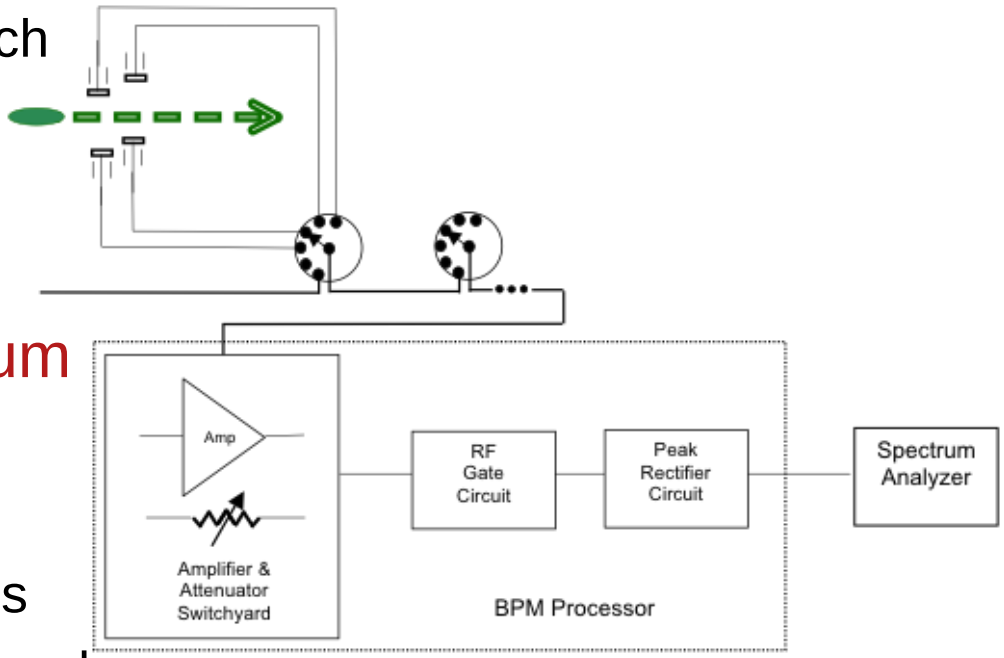
* Provided slides for this talk

Outline

- Description of Measurement Techniques for Observing Unstable Motion
- Example of Typical Instability Observations
- X-ray Beam Size Observations
- Systematic Studies of Electron-cloud-related Instabilities
- Description of Measurement Techniques for Observing the Damped Motion of Bunches Within the Train
- Examples of Observations of Drive-damp Measurements

Measurement Technique for EC-induced Beam Dynamics

- Frequency spectra of individual bunches from single button BPM routed to spectrum analyzer (10 s averaging)
  - Sensitive to both V and H motion
  - Signal is gated on a single bunch
- Machine conditions (e.g. bunch currents, magnet & feedback settings) recorded before and after each spectrum
- Systematic checks:
  - Ruled out inter-modulation distortion in the BPM electronics
  - Betatron and head-tail lines moved as expected when vertical, horizontal, & synchrotron tunes were varied.

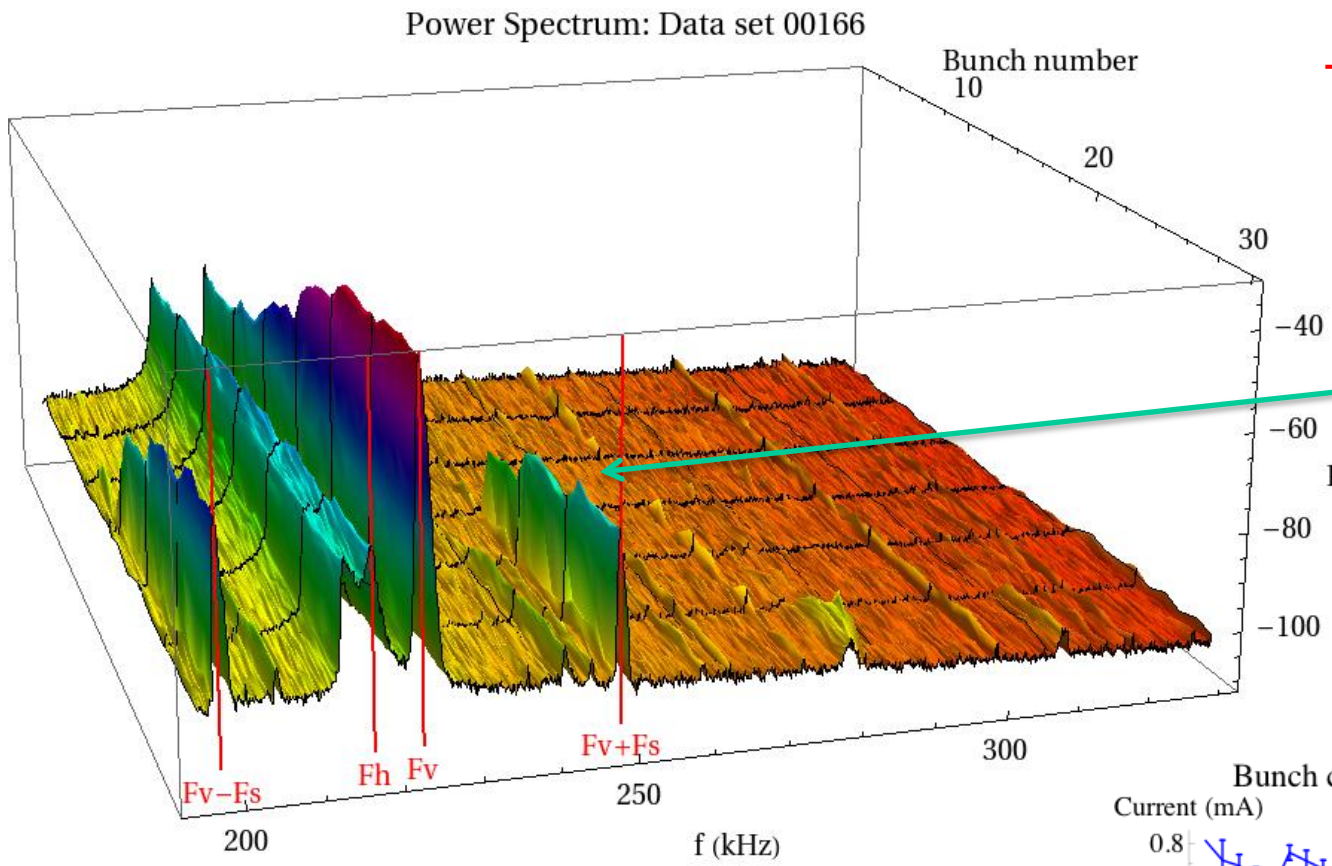


- Conditions: 2.1 GeV, ε_H=2.6 nm, ε_V=20 pm, α_P=6.8x10^{-3}, σ_Z=10.8 mm, Q_H,Q_V,Q_S=14.57, 9.6, 0.065 30-45 bunch trains: 0.5-1 mA (0.8-1.6x10^{10})

EC-induced Beam Dynamics: General Observations

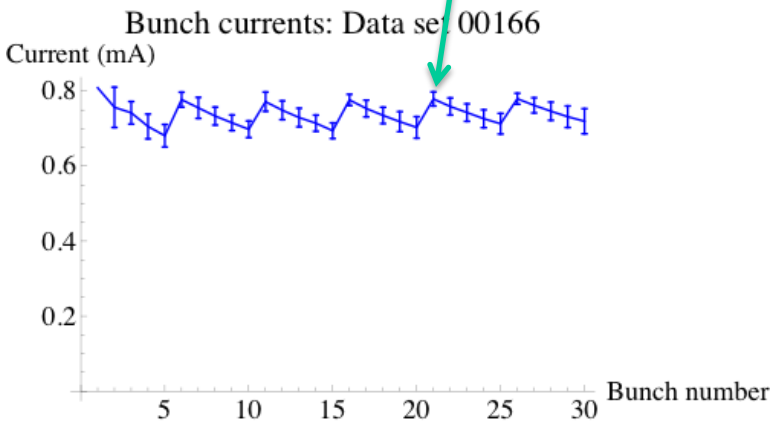
- Frequency spectra exhibit vertical m=+/- 1 head-tail (HT) lines
  - Some bunches in the train show peaks separated from $F_{\beta V}$ by F_{synch}
  - Amplitudes typically grows along the train.
- After 1st bunch where vertical HT lines appear above noise
  - We observe growth in the beam size, continuing to increase along train
- In some cases, 1st bunch in train exhibits a HT line (m=-1).
  - "Precursor" bunch ("clearing" bunch) eliminates m=-1 signal in 1st bunch
  - Without "precursor" bunch vertical beam size is larger for 1st bunch
- Following slides present
  - Details of these observations
  - Dependence on machine and beam parameters such as
    - Current
    - Number of bunches
    - Chromaticity
    - Synchrotron Tune, etc.

Bunch-by-bunch Power Spectrum: Run 166



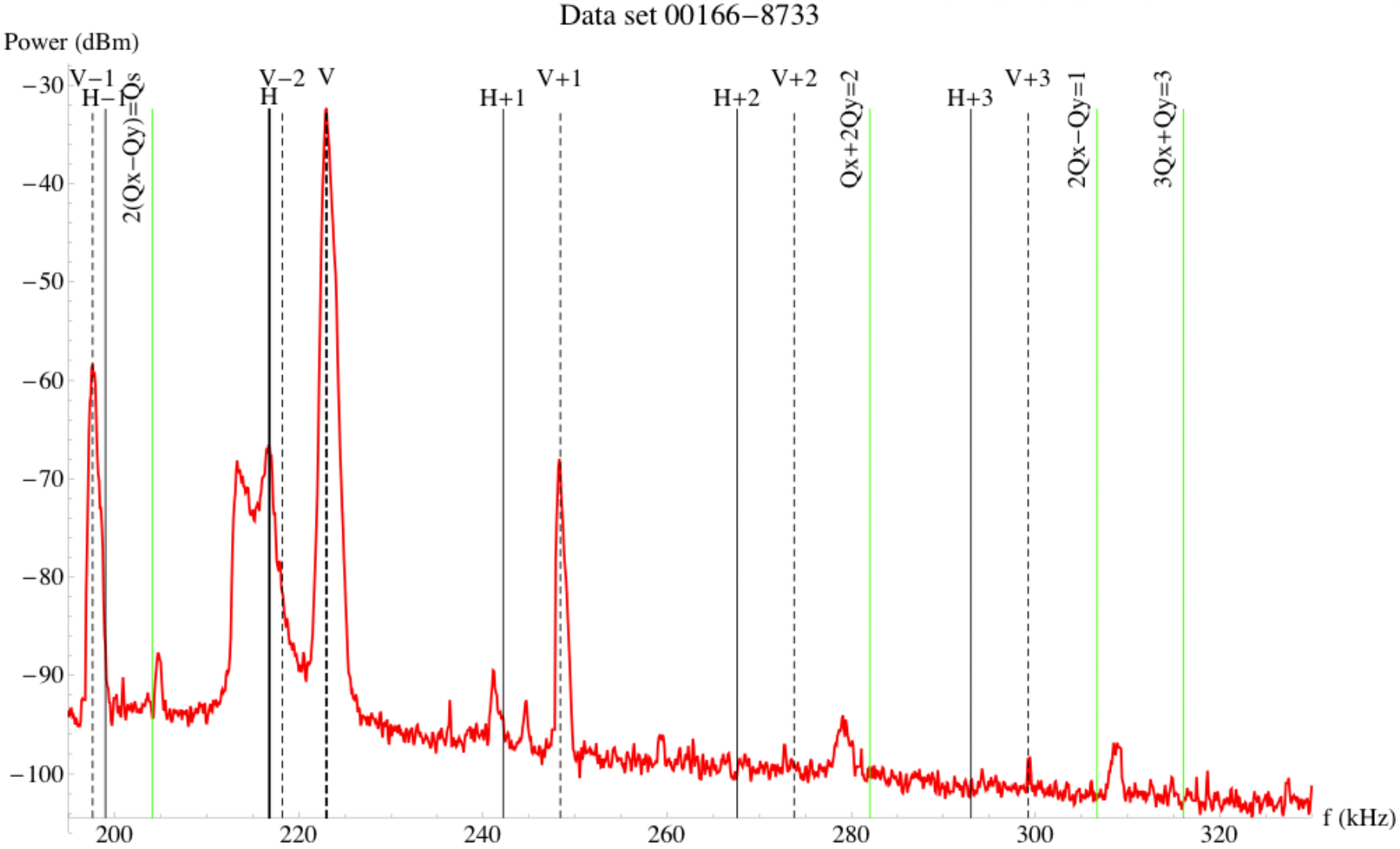
This is a representative example of the bunch-by-bunch power spectrum

Scallops in the power spectra are due to topping off the bunch currents

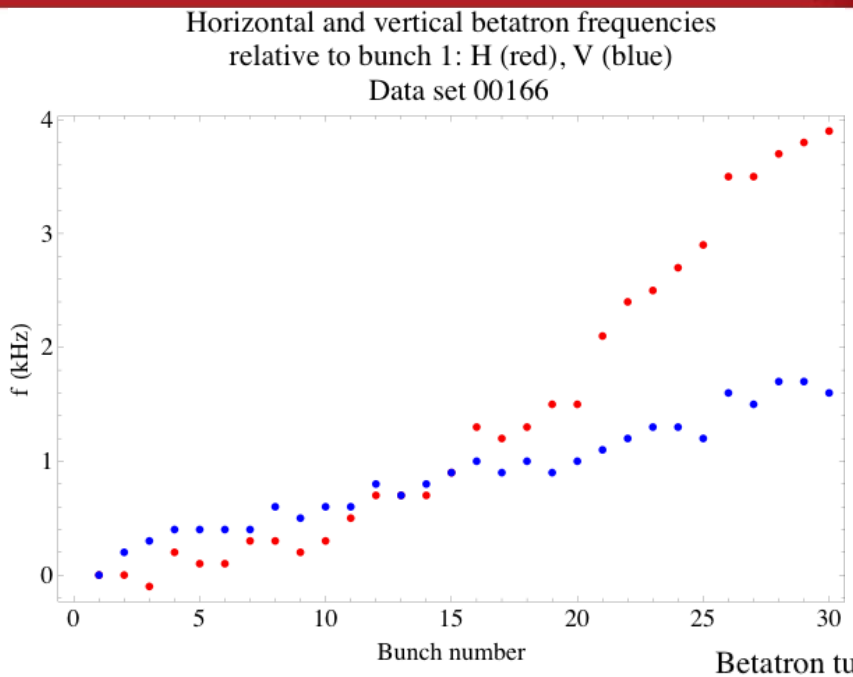


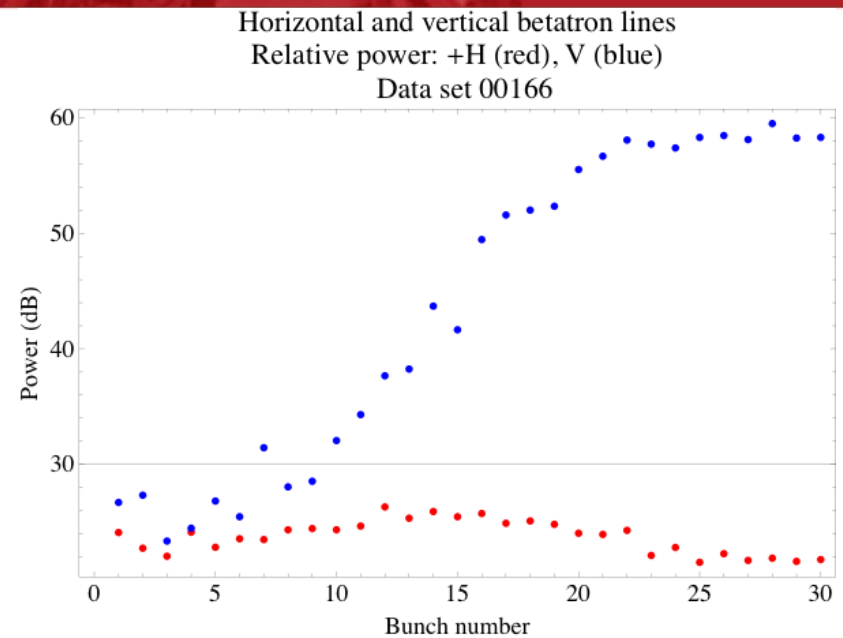
(H,V) chrom = (1.33,1.155)
Avg current/bunch 0.74 mA.

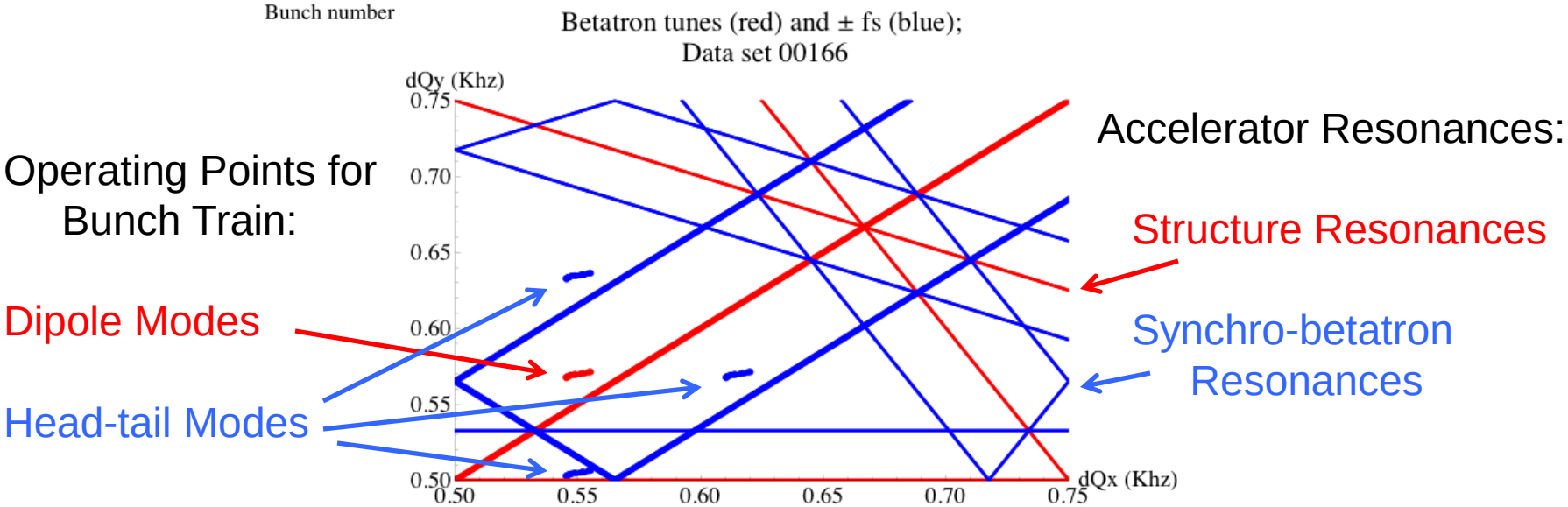
Detail of Spectrum of Bunch 30: Run 166



Horizontal and Vertical Betatron Lines: Run 166

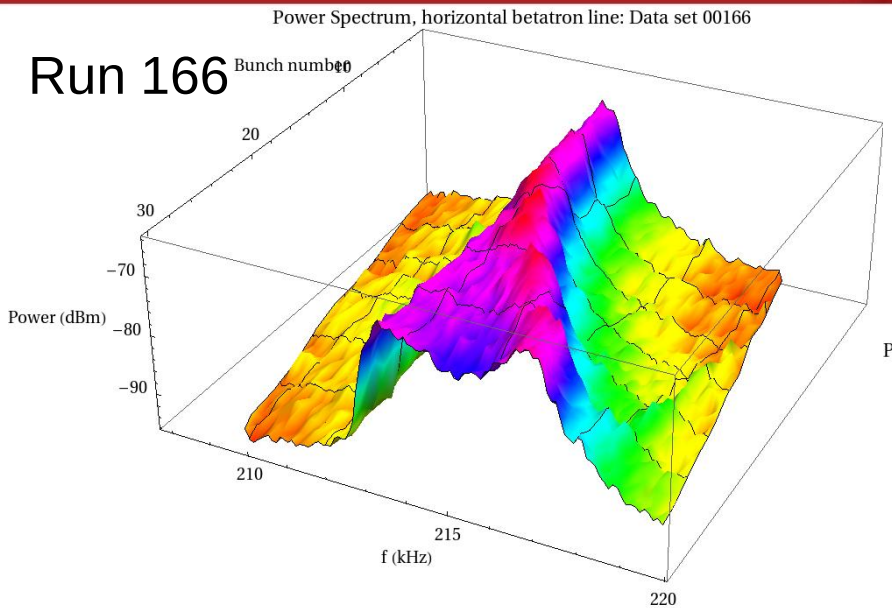




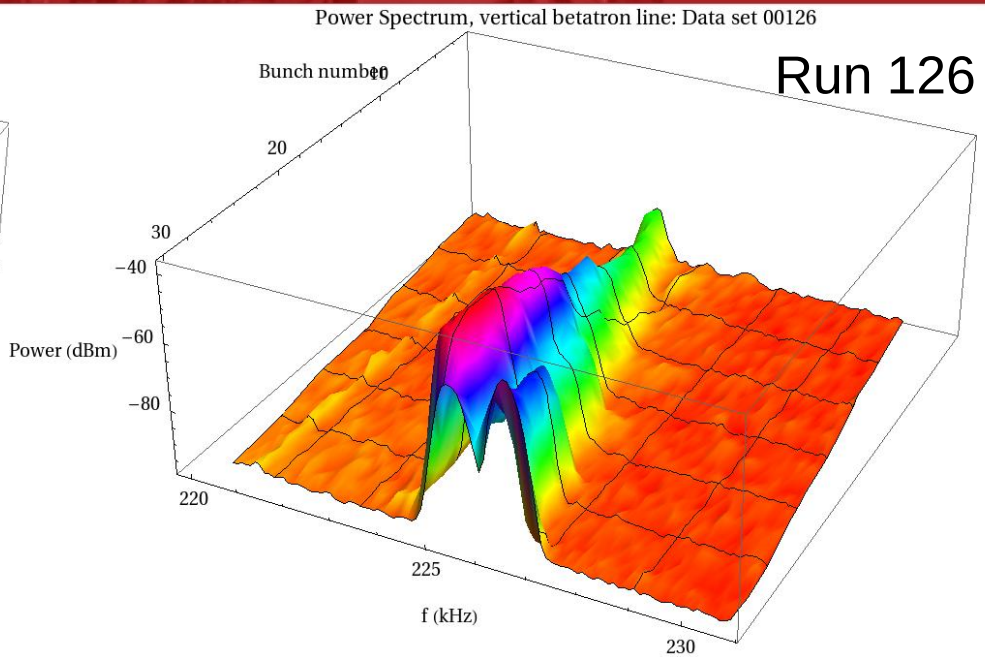


Detailed Features of Horizontal and Vertical Lines

Run 166



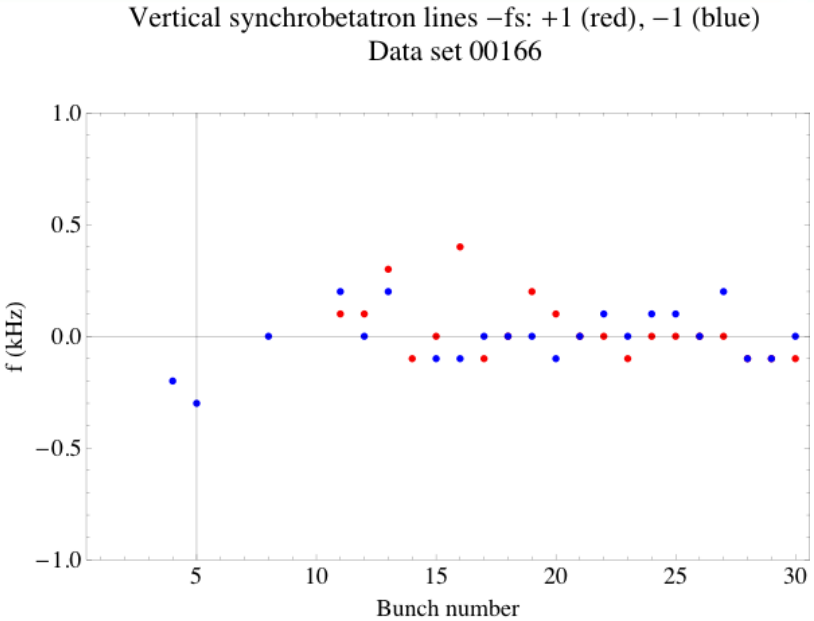
Run 126

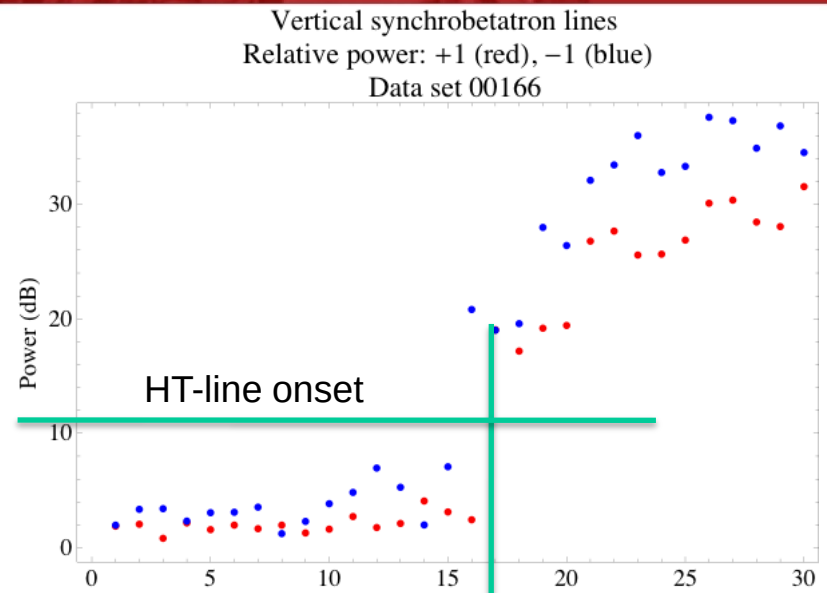


Lower frequency (~3 kHz) shoulder in the horizontal tune spectrum is attributable to known dependence of horizontal tune on the multibunch mode.

Bifurcation of the vertical tune spectrum (peak at ~ 1.5 kHz higher frequency) , which starts to develop at the same bunch number as the head-tail lines, is not yet understood.

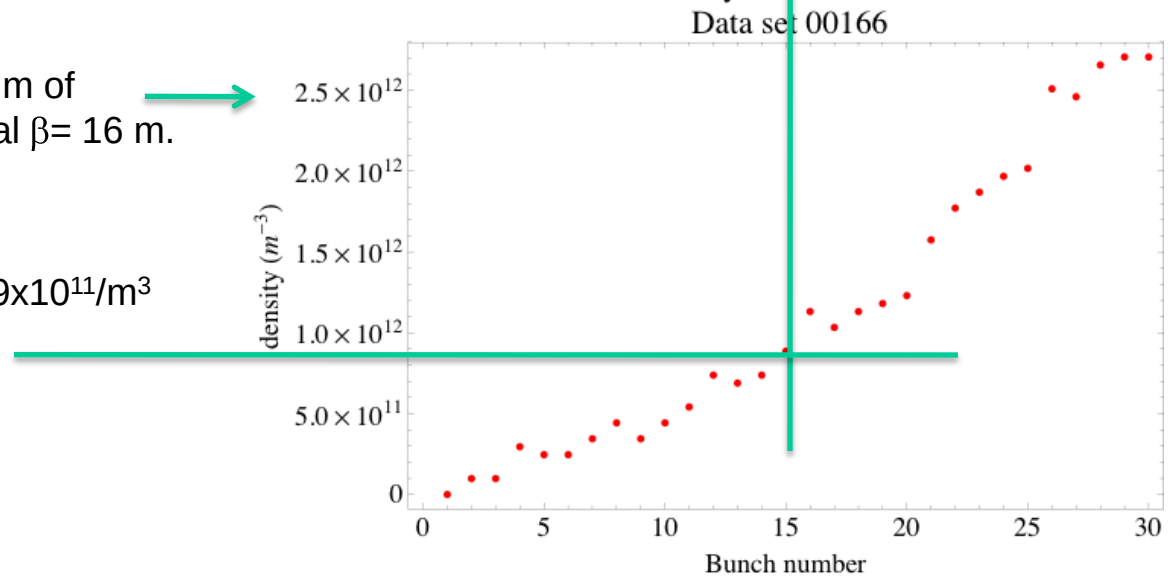
Vertical Head-tail Lines: Correlation with Cloud Density – Run 166





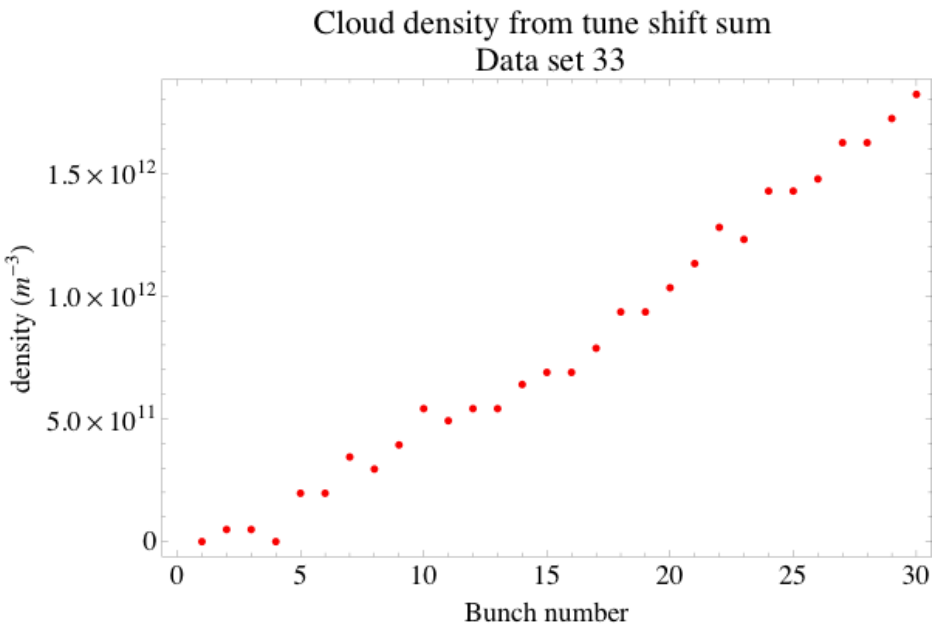
From tune shift data. Assumes 474 m of dipoles, equal vertical and horizontal β= 16 m.

Cloud density at HT-line onset: ~8-9x10^{11}/m^3

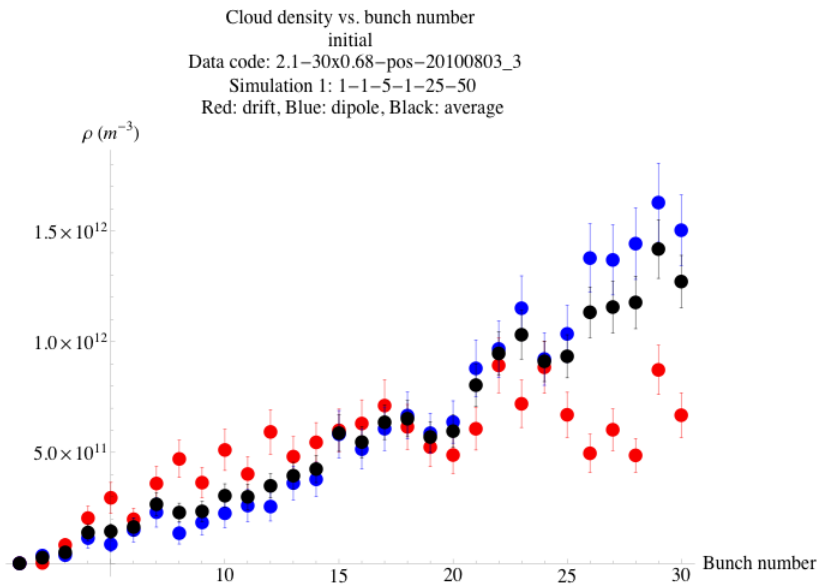


Cloud Density Comparisons

From tune shift data, run 33. Assumes 474 m of dipoles, equal vertical and horizontal β= 16 m.

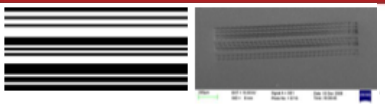


From simulation

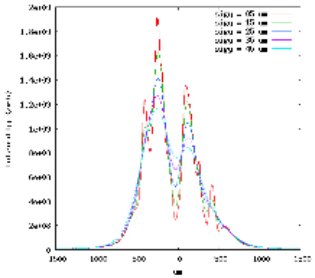


The average cloud density computed directly (but approximately) from the tune shifts agree relatively well with that from a cloud simulation which reproduces the measured tune shifts.

X-ray Beam Size Measurements

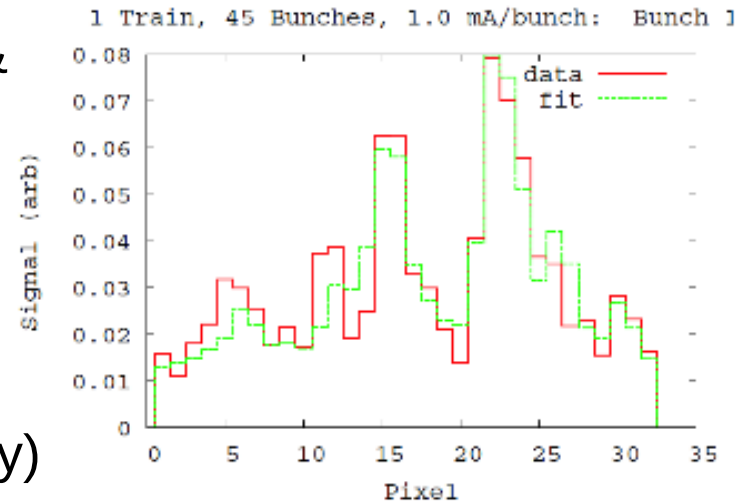


Uniformly Redundant Array (URA) for x-ray imaging being used at CesrTA. Pseudo-random pattern gives relatively flat spatial frequency response.

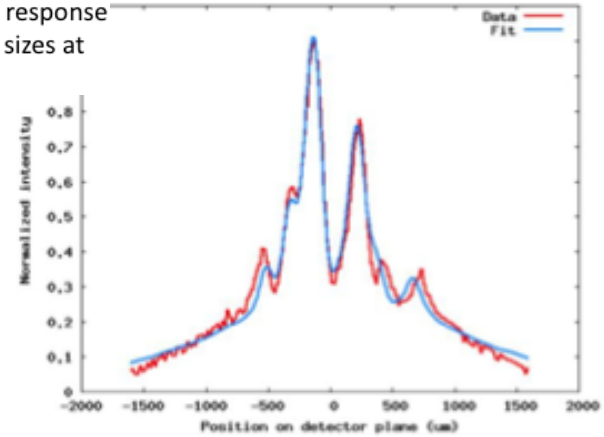


Simulated detector response for various beam sizes at CesrTA

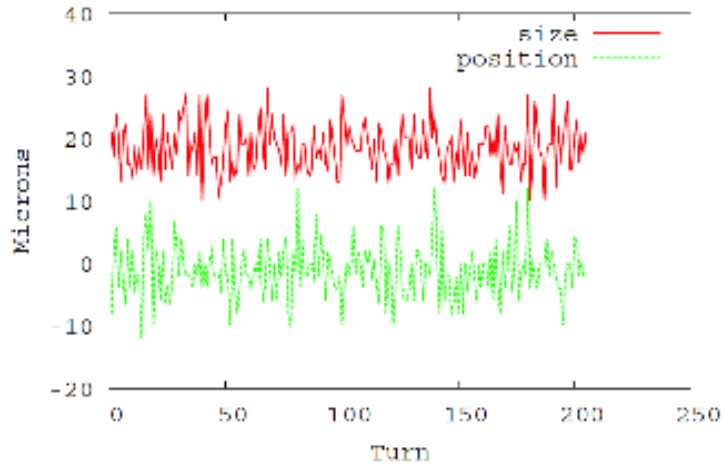
- xBSM uses various optics
  - e.g. Coded Aperture (CA) & Fresnel Zone Plate (FZP) observed on Linear Array
  - Analysis: utilize Point Response Functions to fit for beam size & centroid position (trajectory)



Example of single-shot data (single-bunch, single-turn)



Measured slow-scan detector image (red) at CesrTA, used to validate simulation (blue)



Example of turn-by-turn data (one bunch out of train)

Vertical Beam Size: 45 Bunch Train

Conditions

14 nsec spacing

Full feedback gains

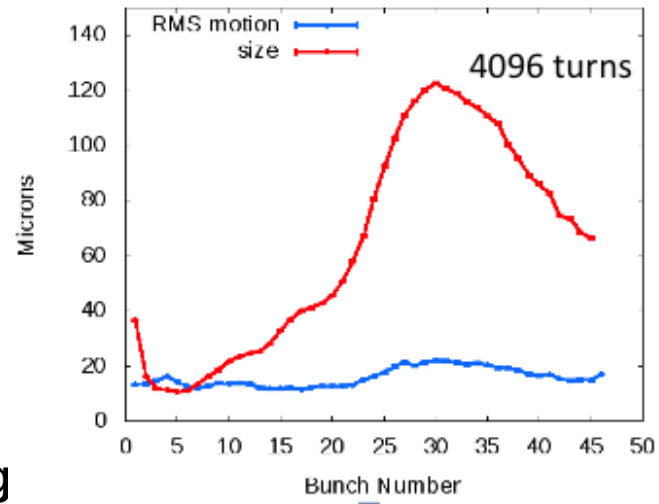
Observation

Substantial V motion beginning at ~ bunch 25

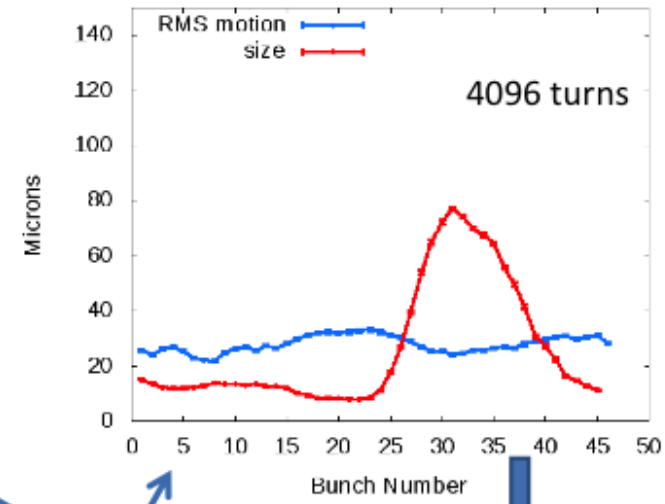
Show increase in σ_V by bunch 20-25

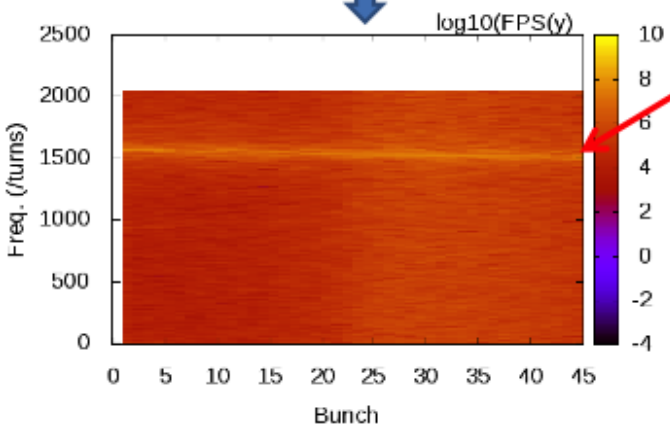
FZP has limited accuracy when σ_V increases

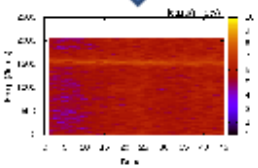
CA



FZP







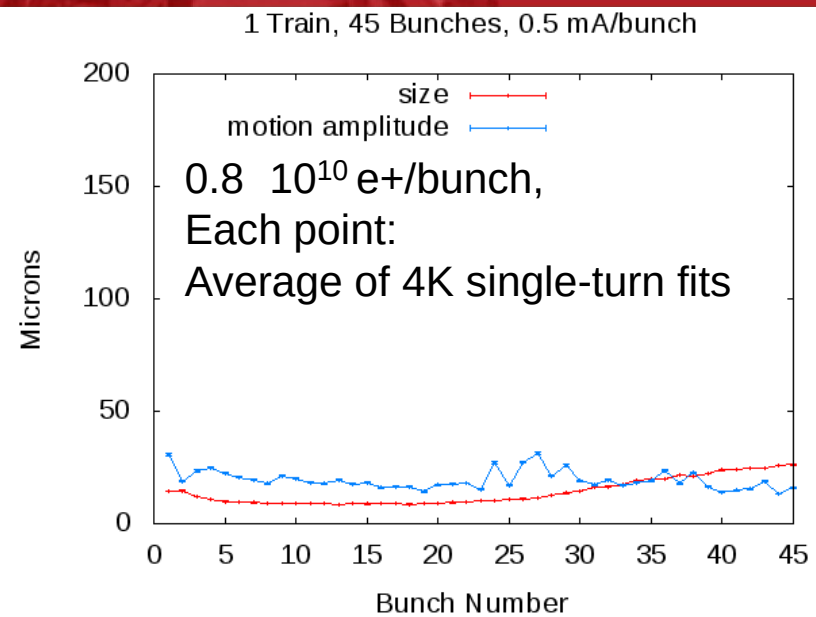
Single-bunch, single-turn fits averaged over turns

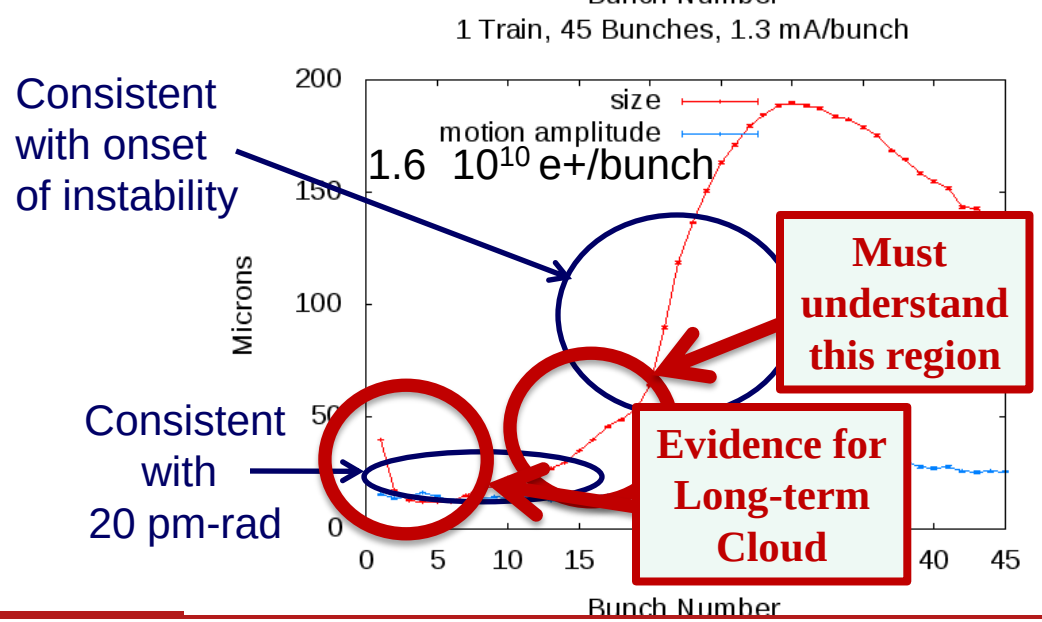
Bunch-by-bunch position spectra

1.3 mA /bunch

EC-Induced Emittance Growth with Strong Feedback for Coupled-bunch Dipole Modes

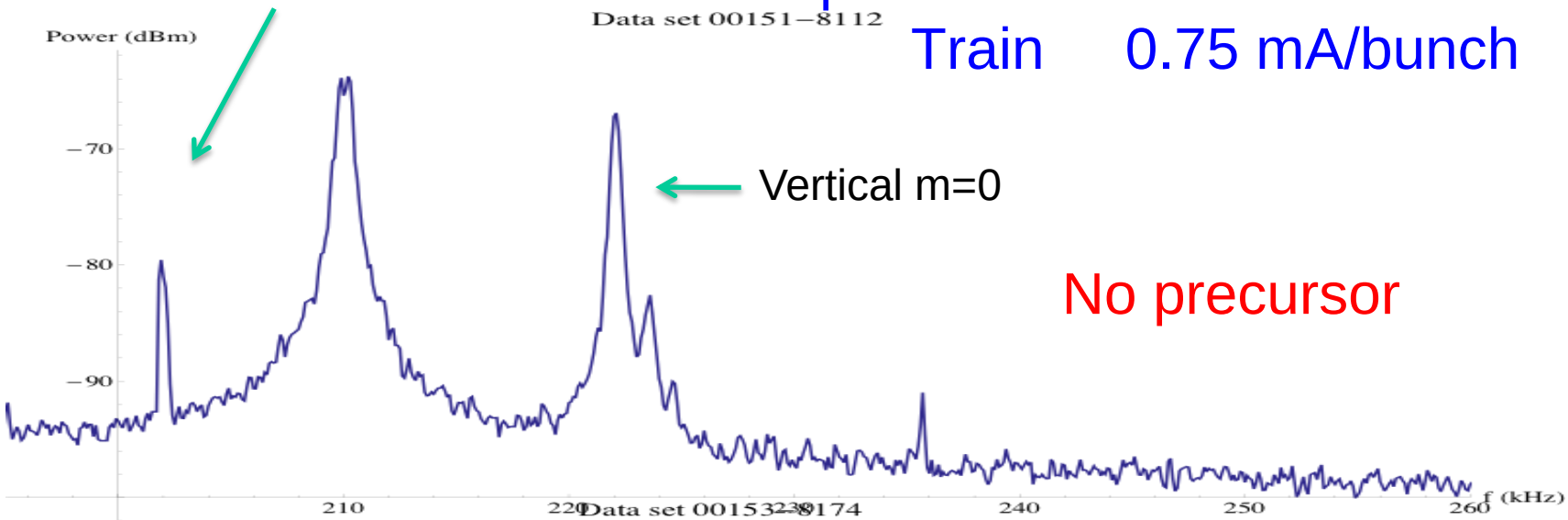
- Measure Bunch-by-Bunch Beam Size
  - Beam size enhanced at head and tail of train
    Source of blow-up at head appears to be due to a long lifetime component of the cloud.
    Bunch lifetime of smallest bunches consistent with observed single bunch lifetimes during LET (Touschek-limited) and with relative bunch sizes.
  - Beam size measured around bunch 5 corresponds to $\varepsilon_y \sim$ 20pm-rad [σ_y=11.0±0.2 μm, β_{source}=5.8m]
  - Large vertical dipole motion from operating with low feedback levels during the instability measurement period sweeps the beam on & off of the Linear Array → confuses the analysis
    Very recent results from J. Flannagan show that it is possible analyze the turn-by-turn data by selecting the turns when the the beam signal is entirely on the detector.



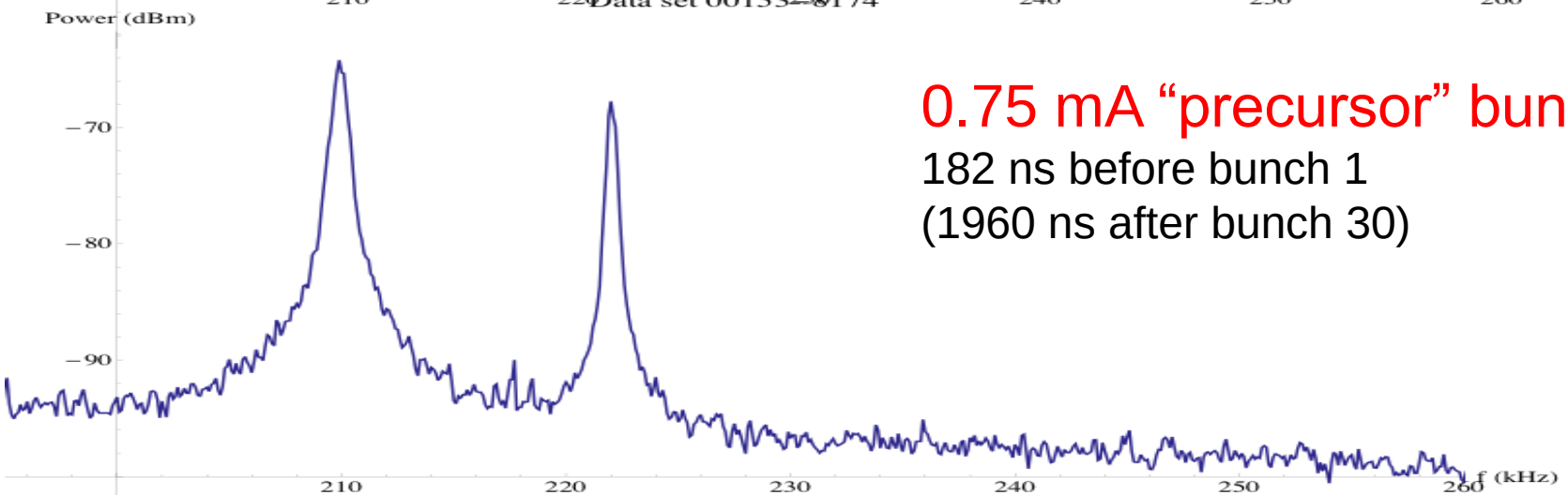


Precursor Bunch Dependence I

Spectrum of Bunch 1 in 30-bunch Train 0.75 mA/bunch



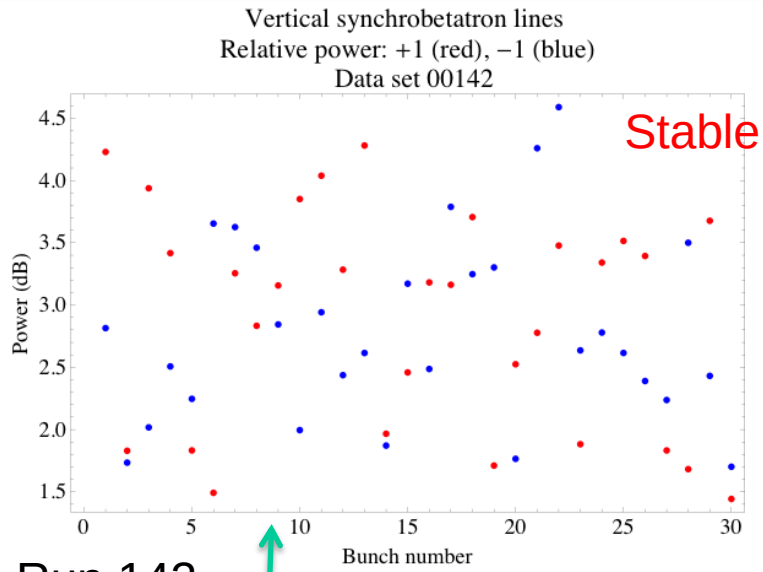
No precursor



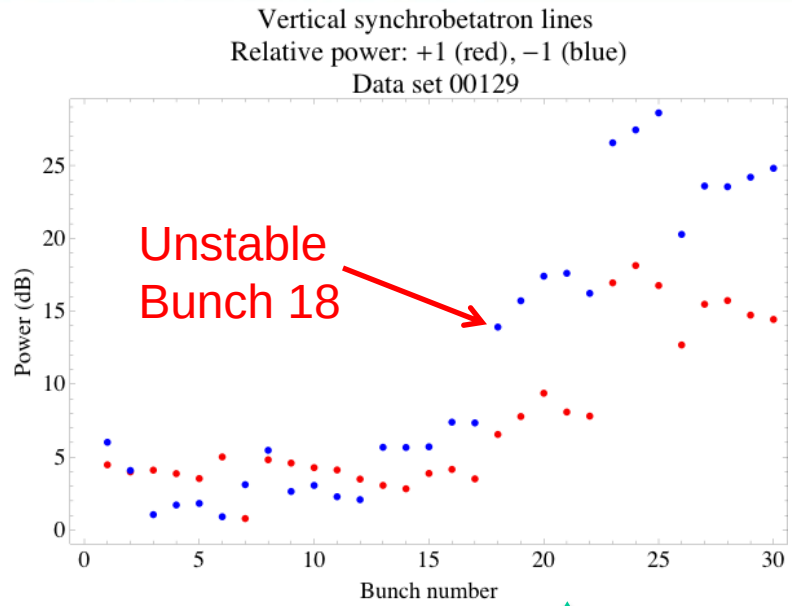
0.75 mA “precursor” bunch:

182 ns before bunch 1
(1960 ns after bunch 30)

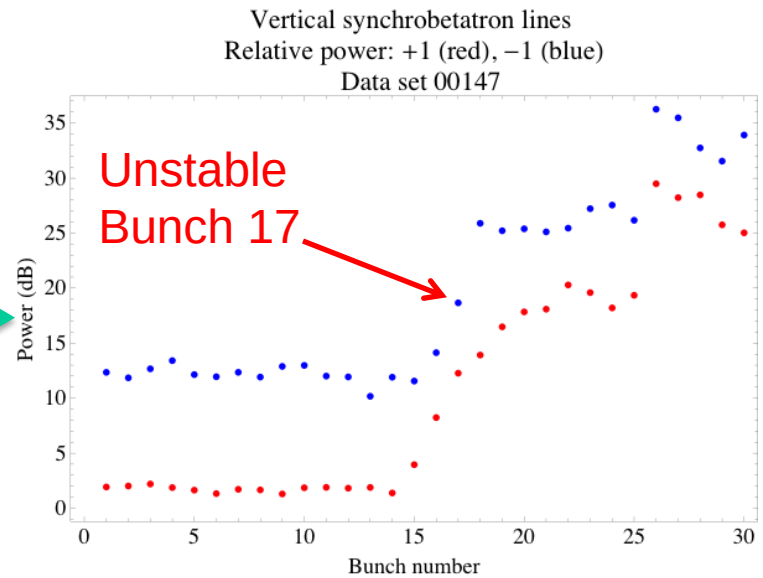
Study of Vertical & Horizontal Chromaticity Dependence



Run 142
V Chromaticity = 1.99
H Chromaticity = 1.34
Nominal current/bunch = 0.736 mA

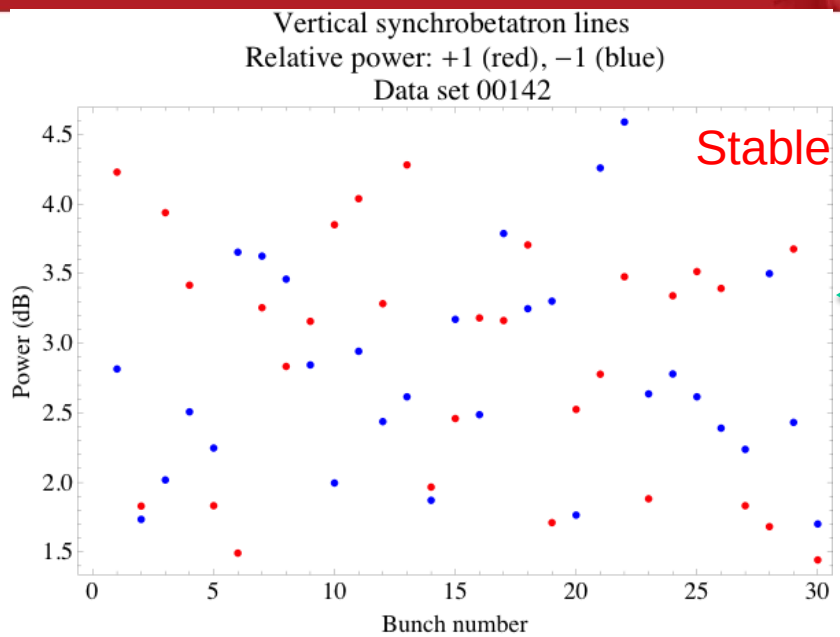


Run 129
V Chromaticity = 1.78
H Chromaticity = 1.07
Nominal current/ bunch = 0.738 mA



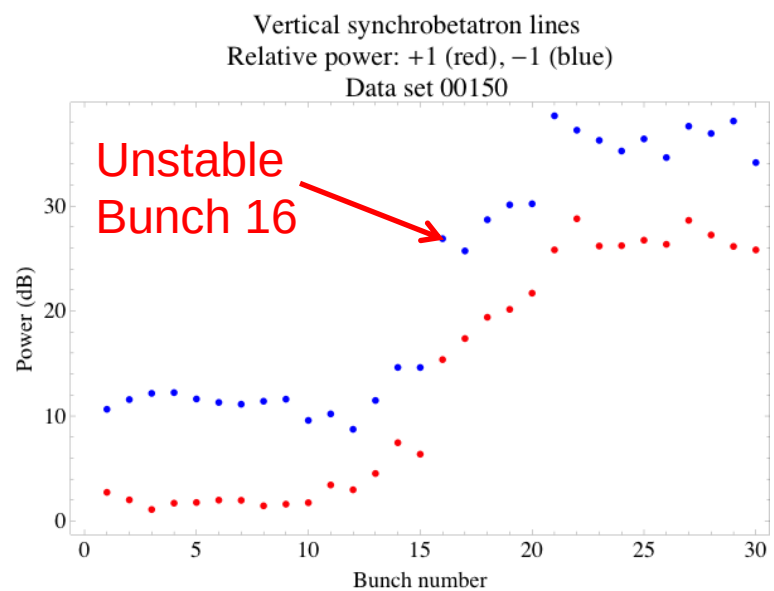
Run 147
V Chromaticity = 1.15
H Chromaticity = 1.33
Nominal current/bunch = 0.735 mA

Study of Current Dependence I

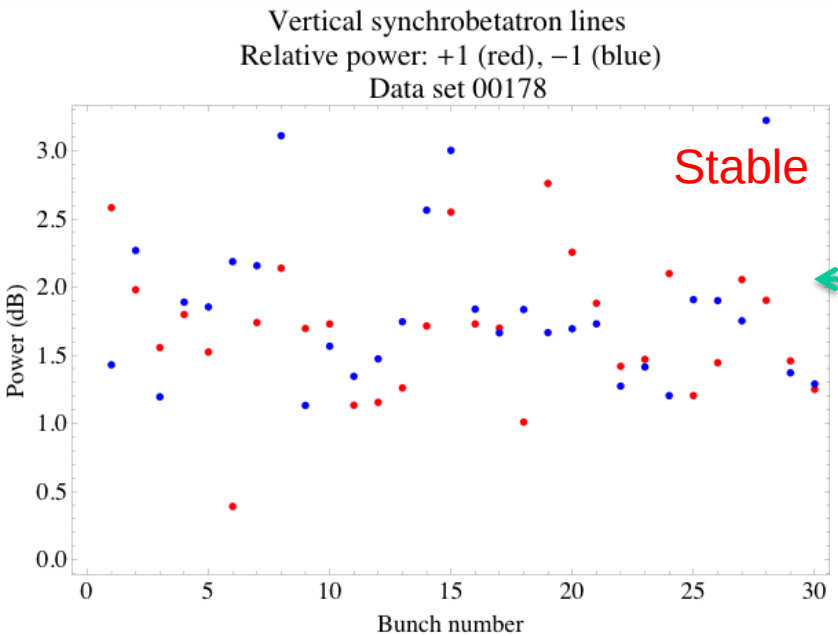


Run 142
V Chromaticity = 1.99
H Chromaticity = 1.34
Nominal current/bunch = 0.736 mA

Run 150
V Chromaticity = 1.99
H Chromaticity = 1.34
Nominal current/bunch = 0.947 mA

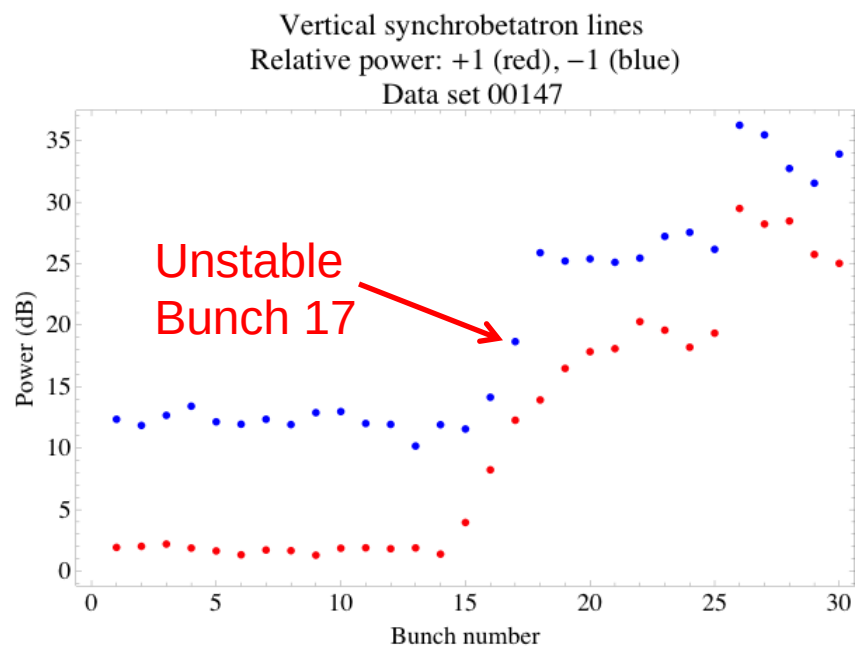


Study of Current Dependence II

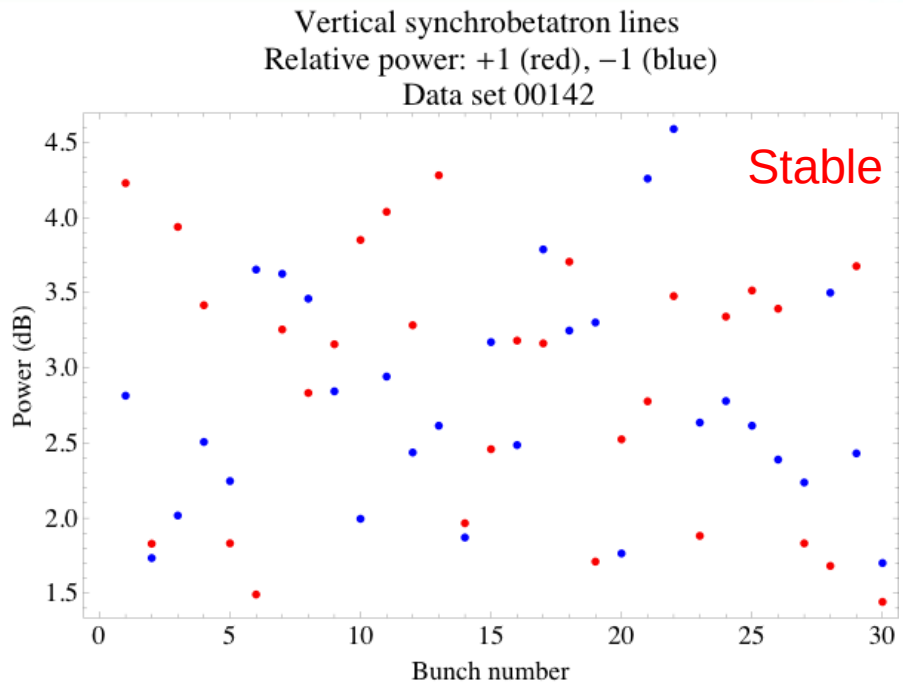


Run 178
V Chromaticity = 1.11
H Chromaticity = 1.34
Nominal current/bunch = 0.5 mA

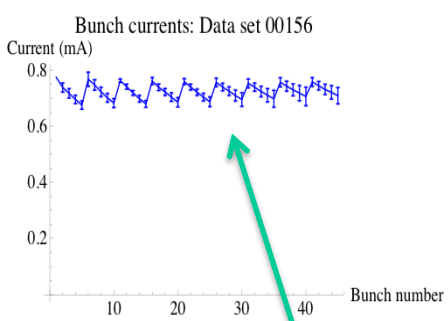
Run 147
V Chromaticity = 1.11
H Chromaticity = 1.34
Nominal current/bunch = 0.736 mA



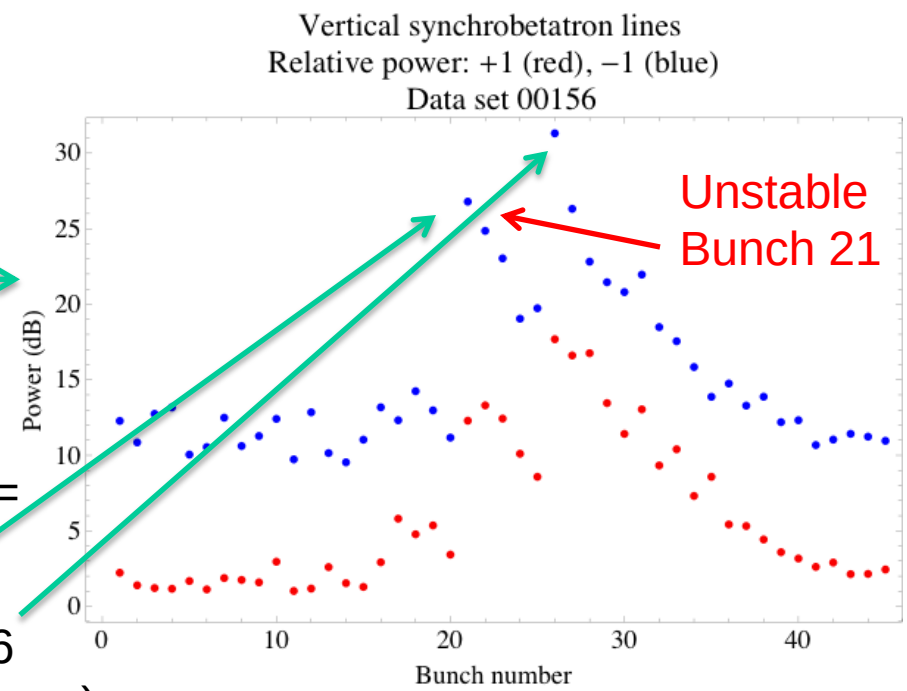
Bunch Number Dependence



Run 142 30 bunches
V Chromaticity = 1.99
H Chromaticity = 1.33
Nominal current/bunch = 0.737 mA



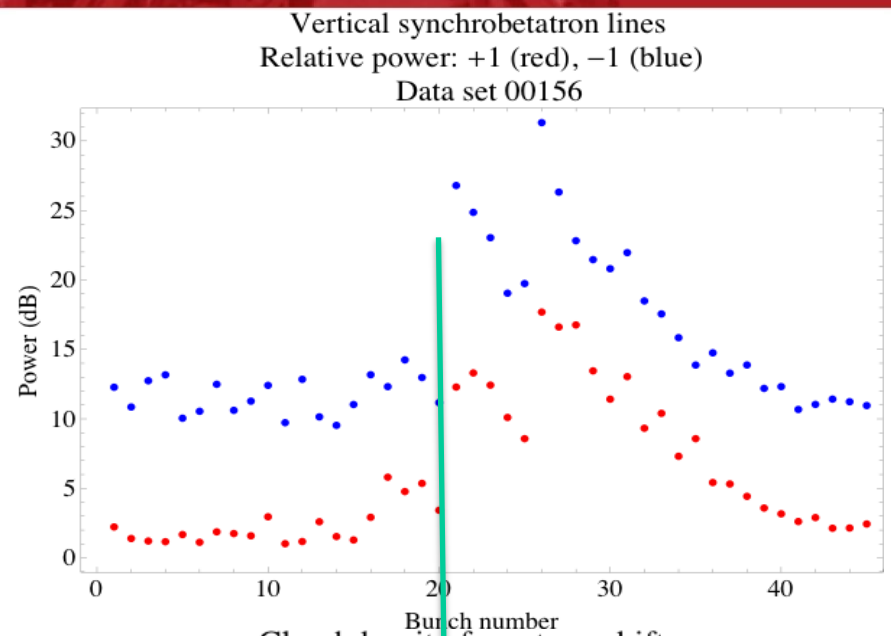
Run 156 45 bunches
V Chromaticity = 1.99
H Chromaticity = 1.33
Nominal current/bunch = 0.725 mA



(increased amplitude at bunches 21 and 26 due to refilling of train at these bunch numbers)

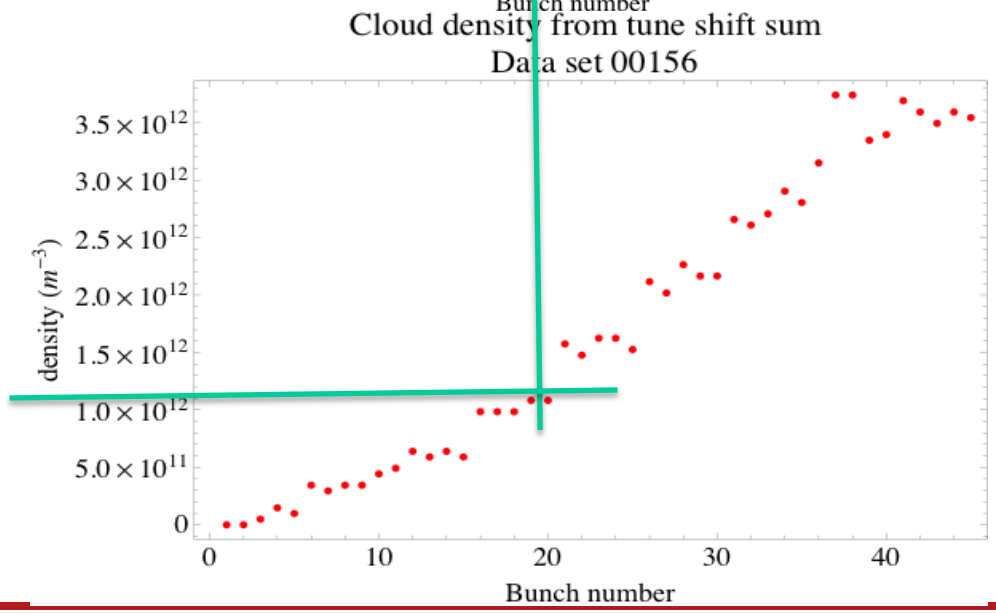
HT Line - Cloud Density Correlation: 45 Bunches

Run 156 45 bunches
V Chromaticity = 1.99
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.725

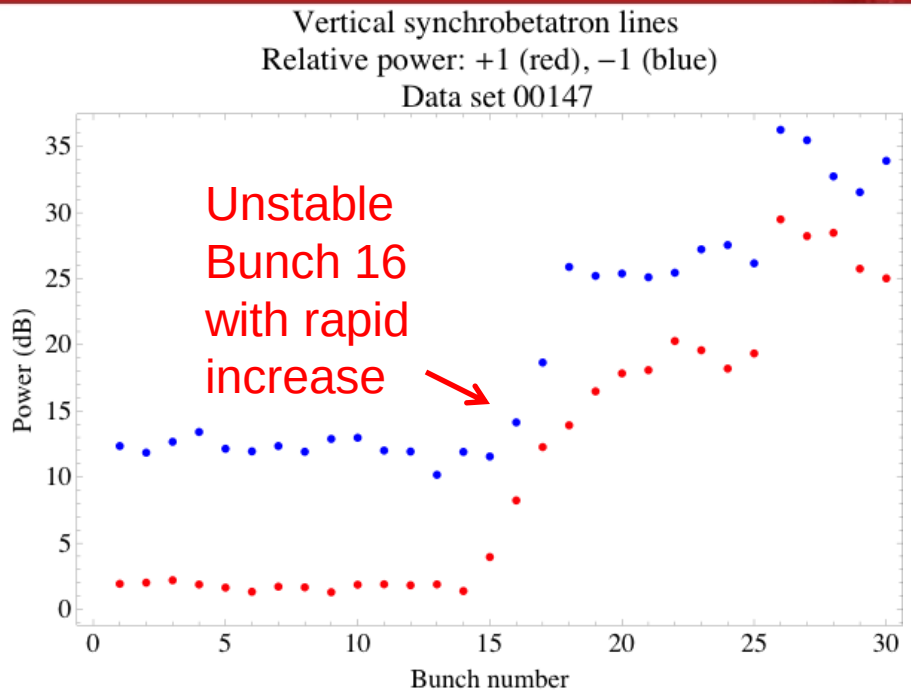


From tune shift data.
Assumes 474 m of dipoles, equal vertical and horizontal β= 16 m.

Onset of HT-lines:
~1.1x10^{12}/m^{-3}

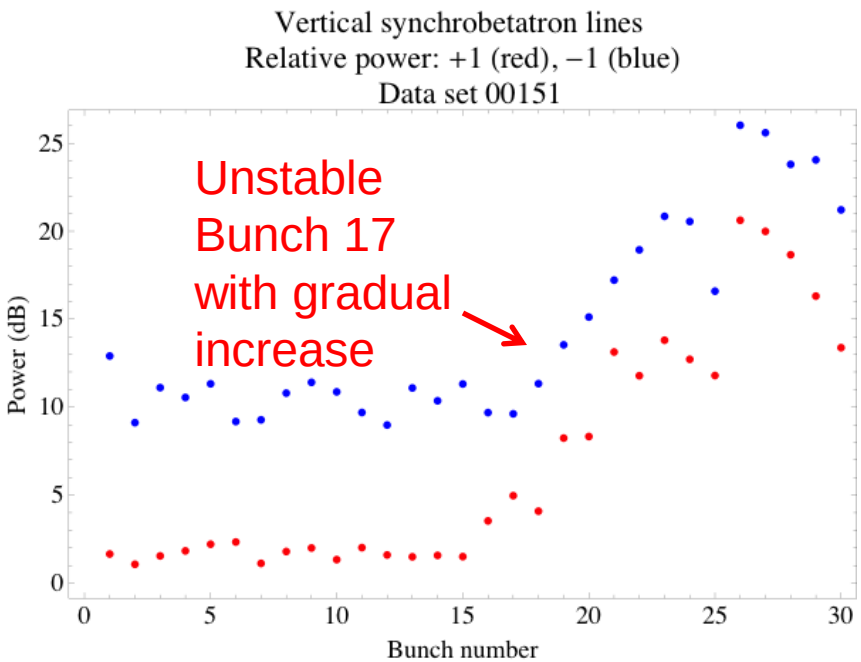


Synchrotron Tune & Bunch Length Dependence

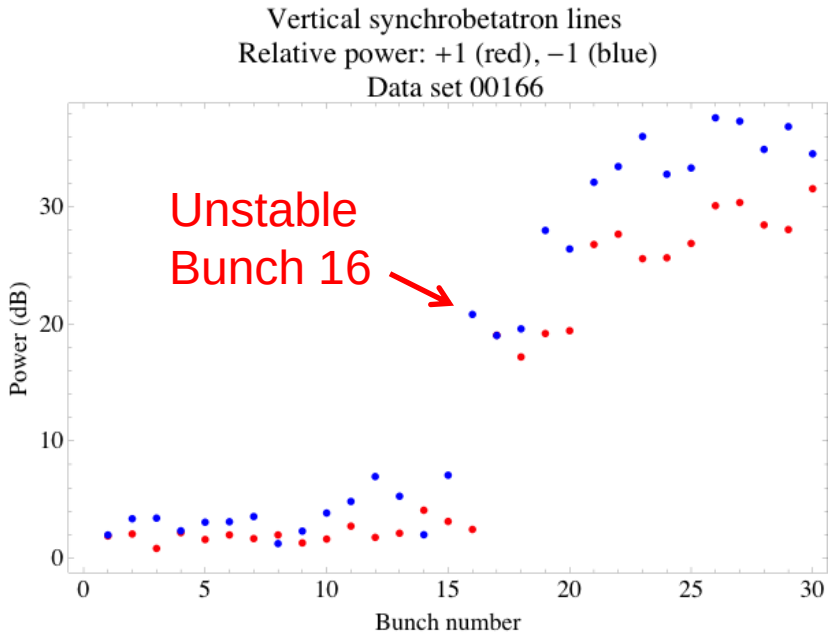


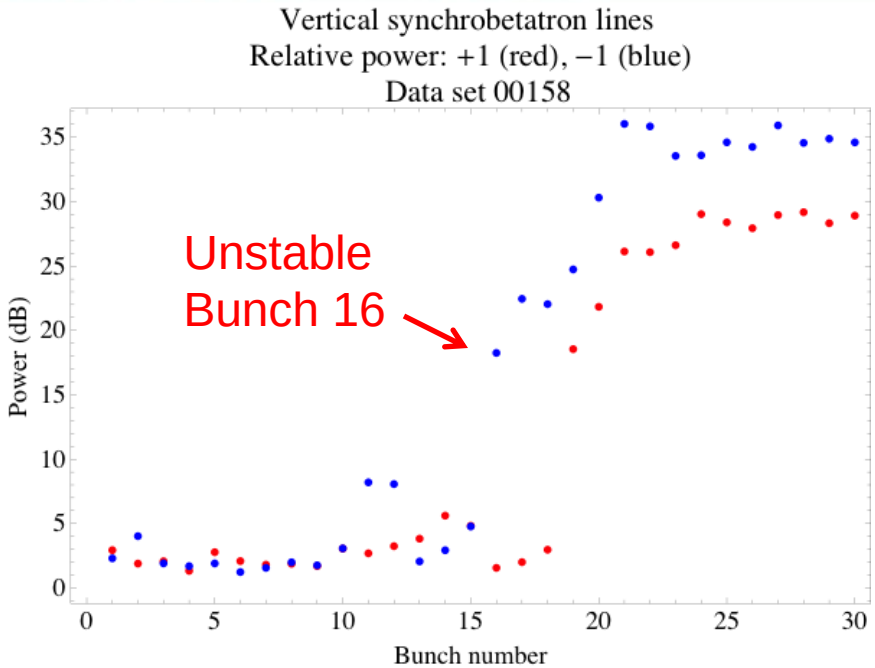
V Chromaticity = 1.15
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.735
Synchrotron tune = 25.4 kHz
Bunch length = 10.5 mm

V Chromaticity = 1.15
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.735
Synchrotron tune = 20.7 kHz
Bunch length = 12.8 mm



Vertical Emittance Dependence: 30 Bunches, 0.75 mA/b



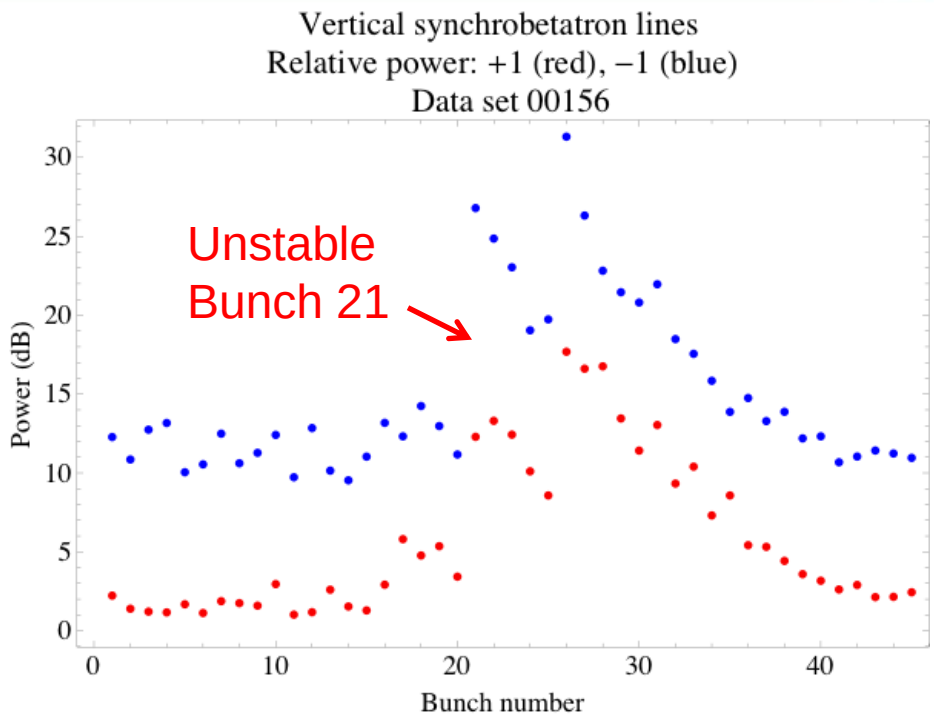


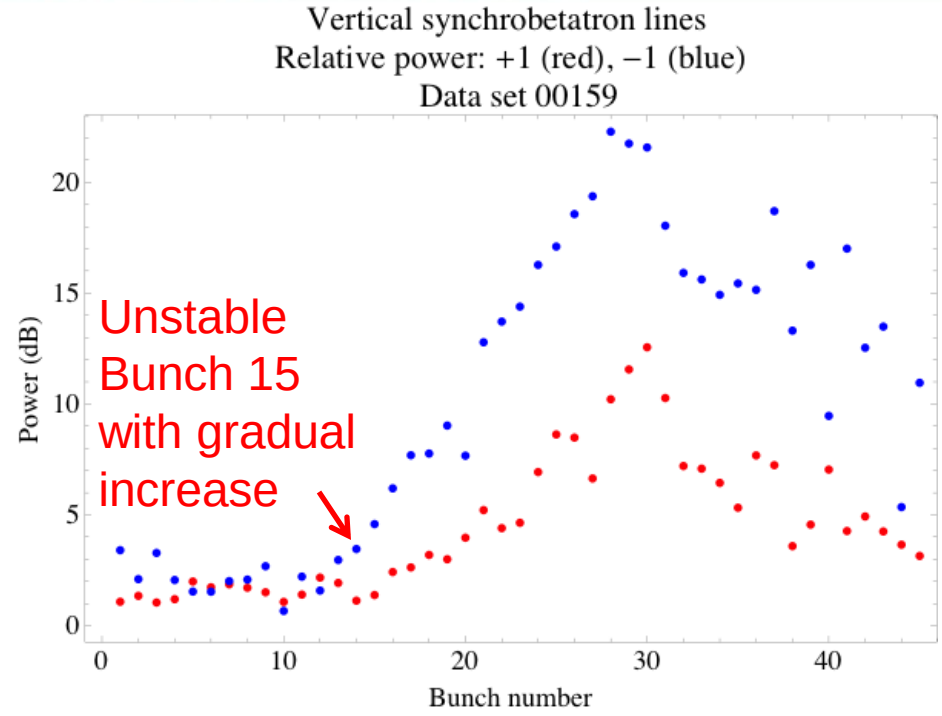
Run 166: 30 bunches
Low vertical emittance (~20 pm)

Run 158:
Increased vertical emittance (~300 pm, estimate, not from measured beam size)

No significant difference for instability

Vertical Emitance Dependence: 45 Bunches, 0.75 mA/b





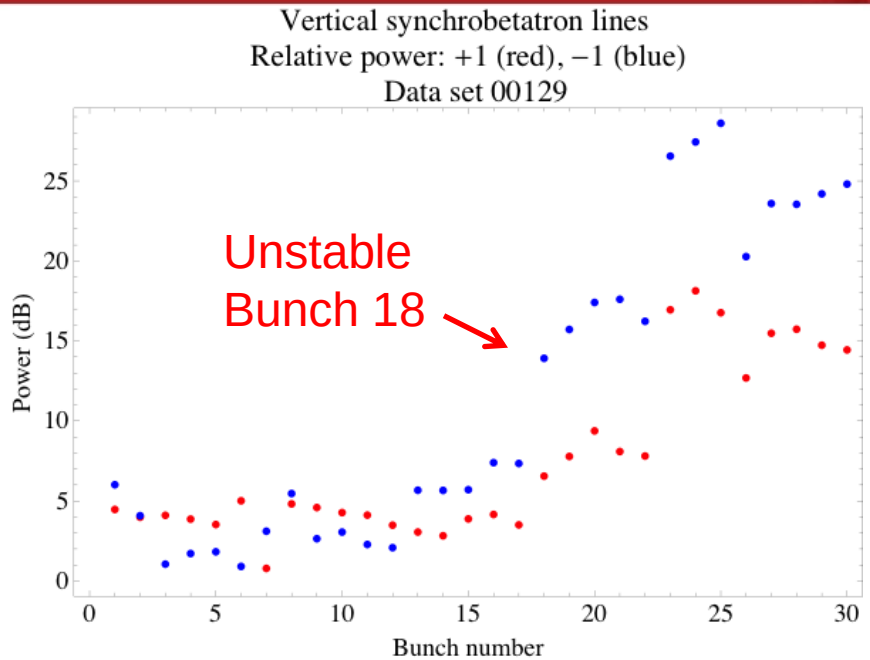
Run 156: 45 bunches
Low vertical emittance (~20 pm)

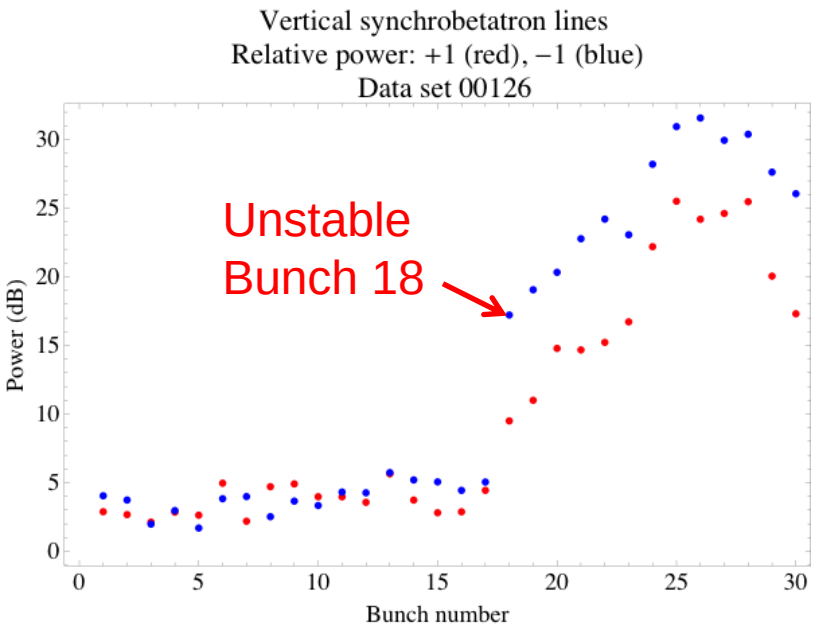
Run 159:
Increased vertical emittance (~300 pm, estimate, not from measured beam size)

Instability starts earlier, but

grows more slowly for higher ε_V

Vertical Feeback Dependence



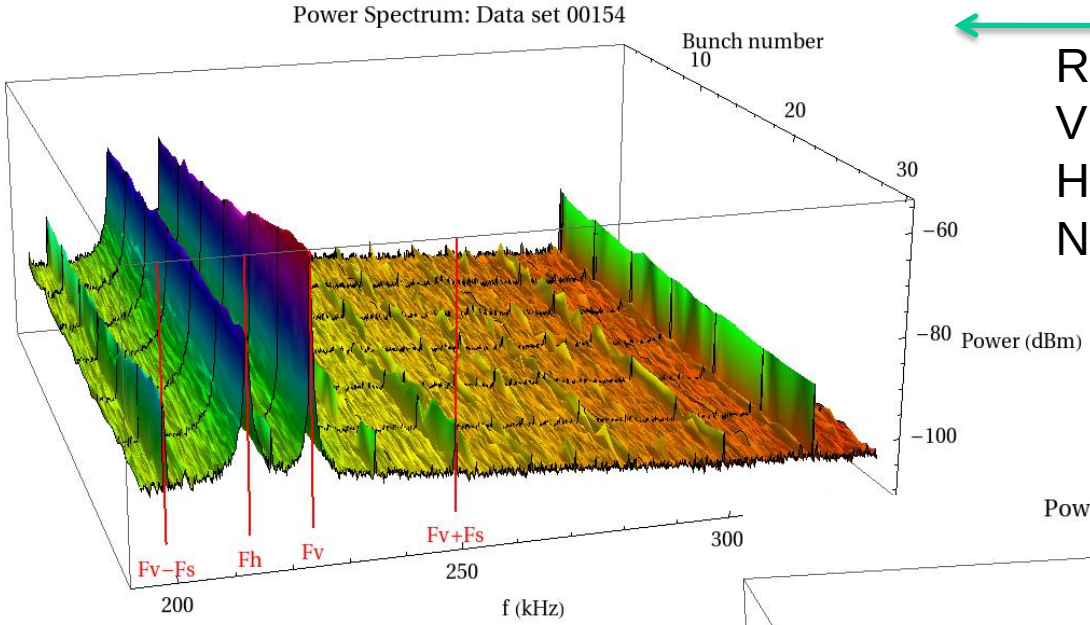


Run 129:
Positron feedback (H,V,L) = (-400, -400, 0)
Nominal current/bunch =0.738 mA

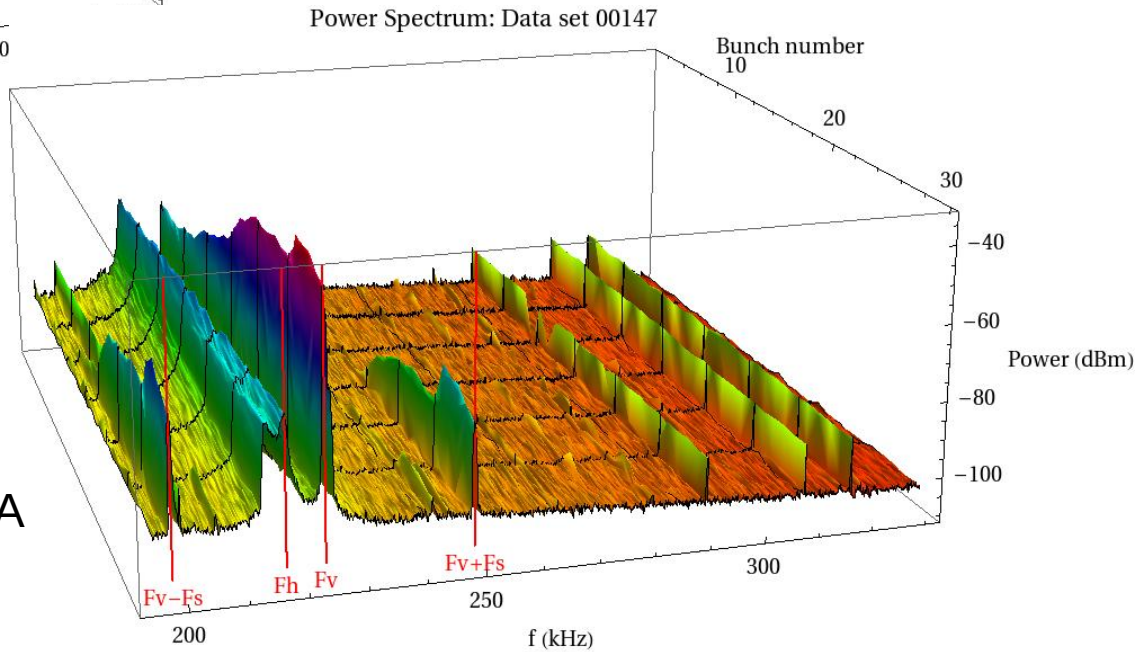
Run 126:
Positron feedback (H, V, L) = (-400, 0, 0)
Nominal current/bunch = 0.723 mA

Dipole vertical feedback does not change the instability threshold for the head-tail modes

Full Spectra: Species Comparison



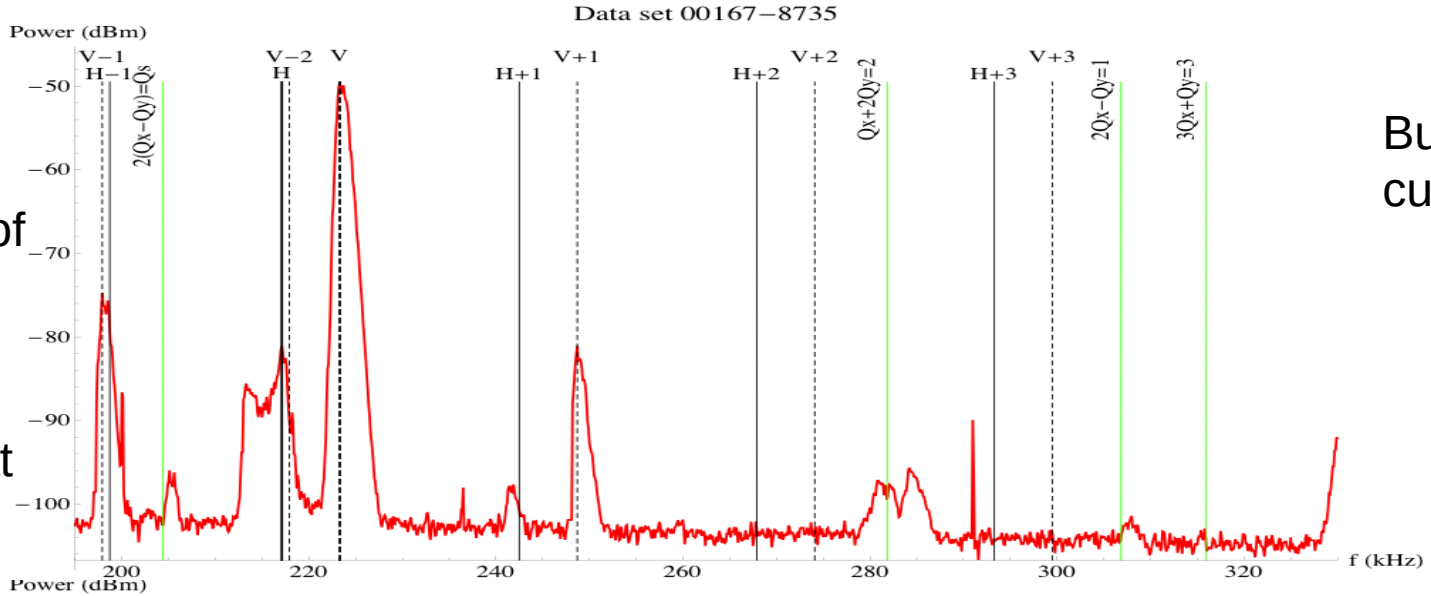
Run 154 Electrons
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch = 0.735 mA



Run 147 Positrons
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch = 0.735 mA

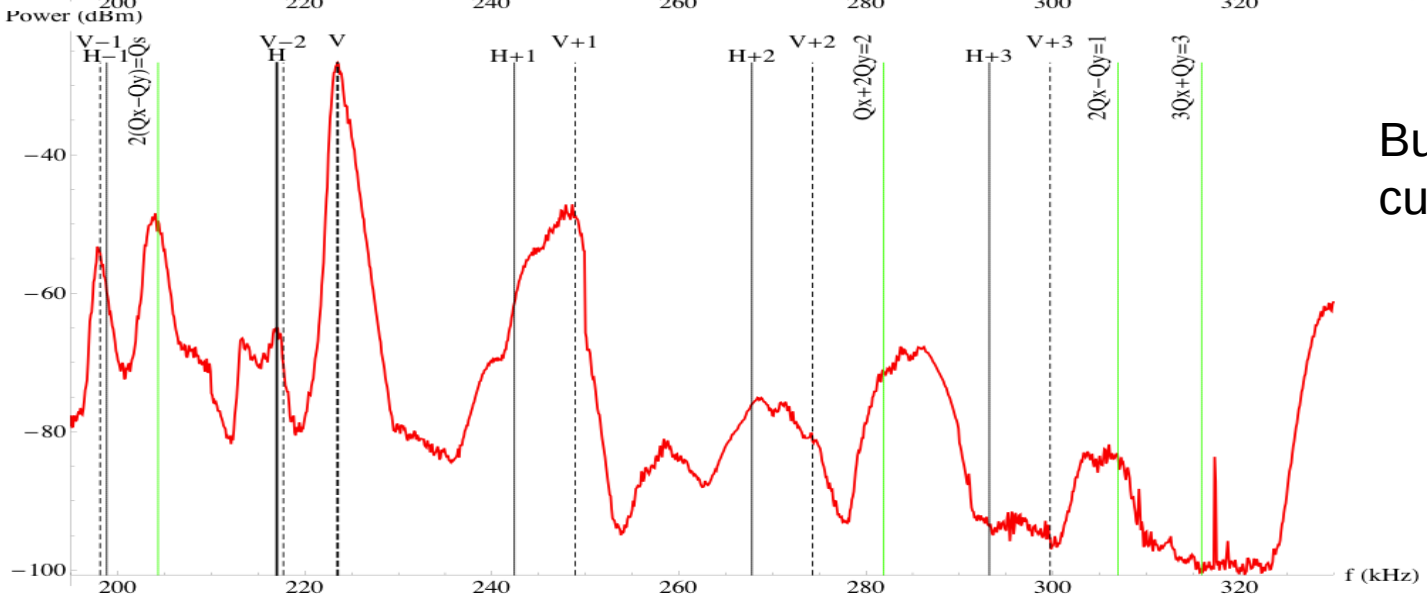
Single Bunch Current Dependence

Spectrum of bunch 30, preceded by 29 bunches at 0.75 mA



Bunch 30 current = 0.25 mA

Positrons



Bunch 30 current = 1.25 mA

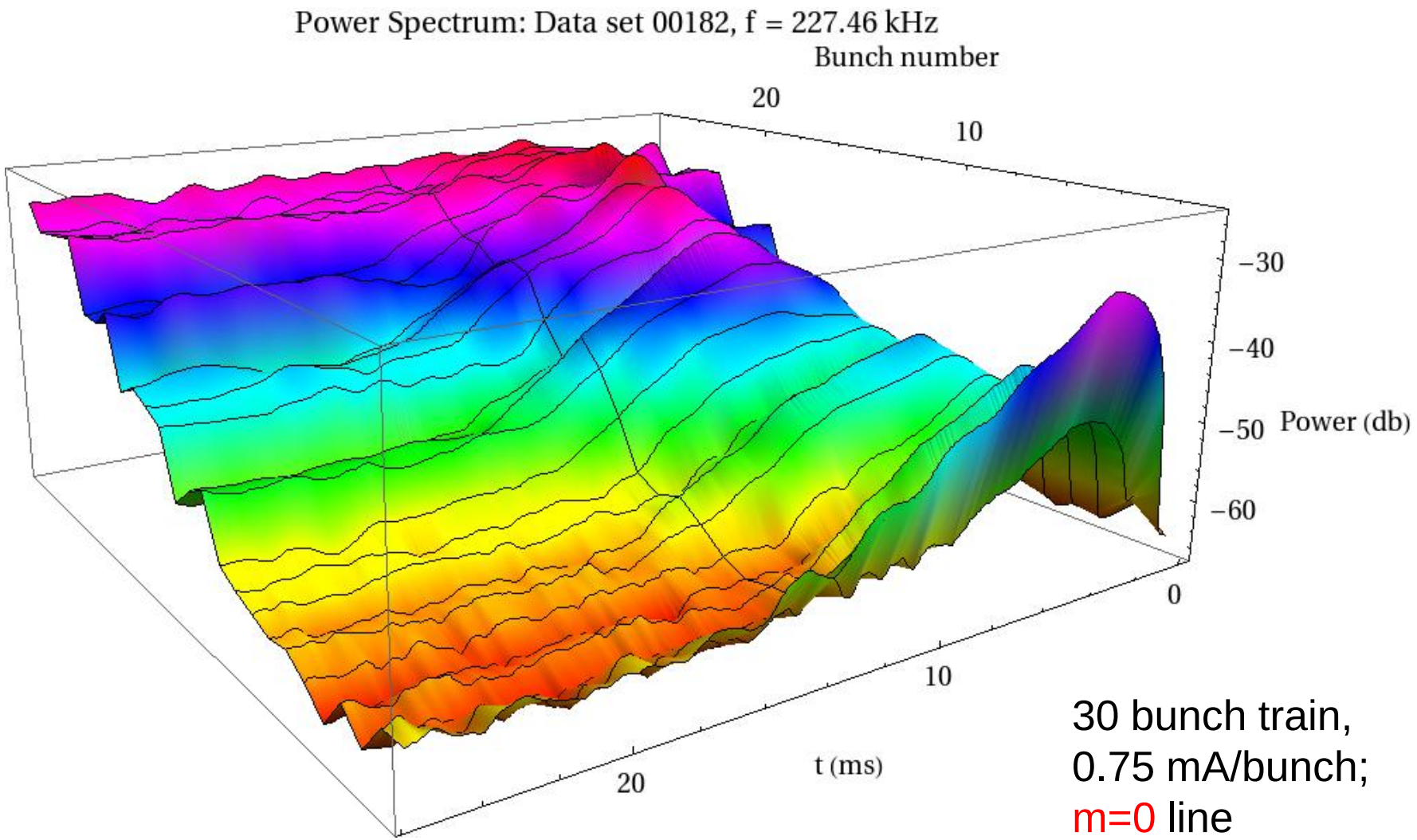
Measurements of Single Bunch Damping Rates

- Bunch-by-bunch damping rate measurements:
  - m = 0 (dipole) mode:
    - Drive a single bunch via Transverse Feedback System external modulator with a pulse
    - Observe the m=0 mode from a button BPM, gated on the same bunch
    - Measure the damping rate of the m=0 line's power after the drive is turned off
  - m = +/-1 head tail modes
    - CW drive of the RF cavity phase – larger amplitude excitation
    - Then use transverse drive-damp excitation, as for m=0 mode
- A number of measurements were made to investigate the systematics of this technique
- Results will be shown for a couple of runs in which 30 bunch trains with currents of about 0.75 mA/bunch were studied. (For these conditions, the self-excited HT lines start around bunch 15).

Measurements of Single Bunch Damping Rates

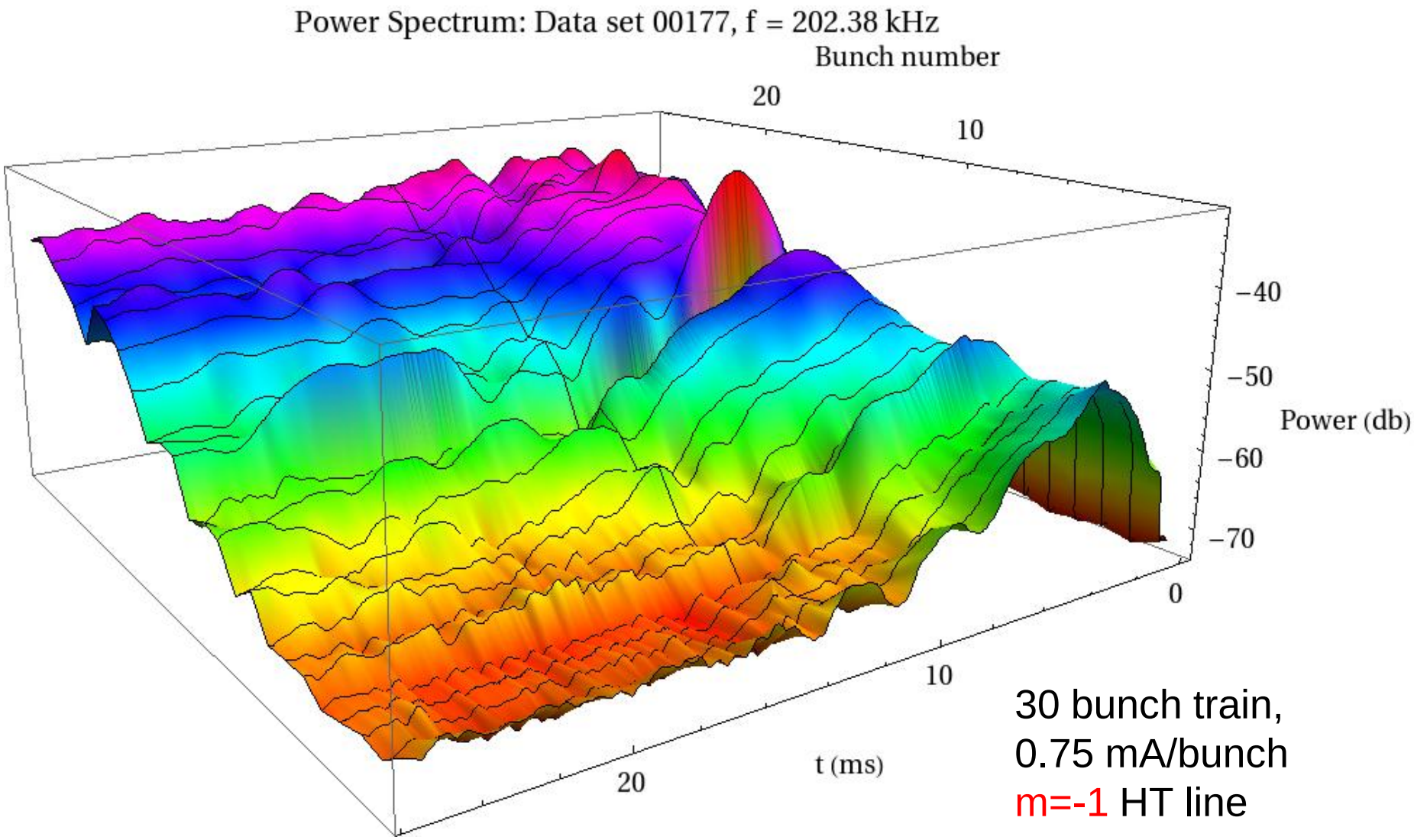
- Bunch-by-bunch damping rate measurements:
  - Basic idea
    - Drive single bunch via Transverse Feedback System external modulator with a pulse
    - Observe spectral line from a button BPM, gated on the same bunch
  - m = 0 (dipole) mode:
    - Measure the damping rate of the m=0 line's power after the drive is turned off
  - m = +/-1 (head tail) modes
    - Apply CW drive to the RF cavity phase – larger amplitude excitation
    - Then use transverse drive-damp excitation, as for m=0 mode
- Number of measurements made to investigate systematics of this technique
- Results for a couple of runs
  - 30 bunch trains
  - Currents of 0.75 mA/bunch
  - For these conditions, the self-excited HT lines start around bunch 15

m = 0 Vertical Betatron Line Grow-Damp Measurement



30 bunch train,
0.75 mA/bunch;
m=0 line

m = -1 HT Line Grow-damp Measurement



30 bunch train,
0.75 mA/bunch
m=-1 HT line

Conclusions

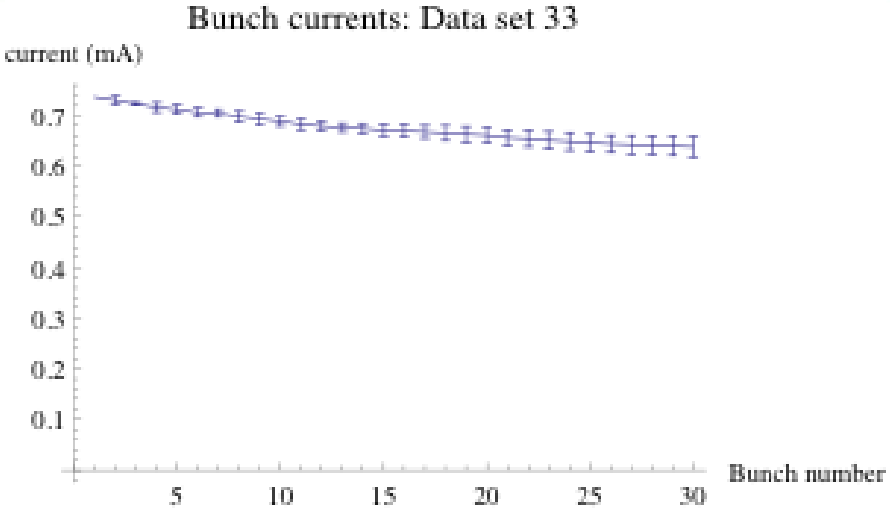
- In single-bunch frequency spectra of multi-bunch positron trains
  - For some of the bunches within train
  - Observed m=+/- 1 head-tail (HT) lines, separated from $F_{\beta V}$ by +/- F_{Synch}
- Onset of HT lines
  - 30 bunch train (0.75 mA/bunch)
  - Occurs at cloud density (near the beam) ~ $9 \times 10^{11}/m^{-3}$ (rough agreement with simulation)
  - Depends on the vertical chromaticity, beam current & number of bunches
  - Weak dependence on F_{Synch}, σ_V, & vertical feedback
- Betatron lines
  - Exhibit structure varying along train
  - Power for $F_{\beta V}$ line grows along train & has structure - not yet understood.
- For 45 bunch train
  - HT lines onset ~ $11\text{-}12 \times 10^{11}/m^{-3}$
  - Maximum amplitude occurs around bunch 30-35
  - Amplitude of line is reduced for later bunches

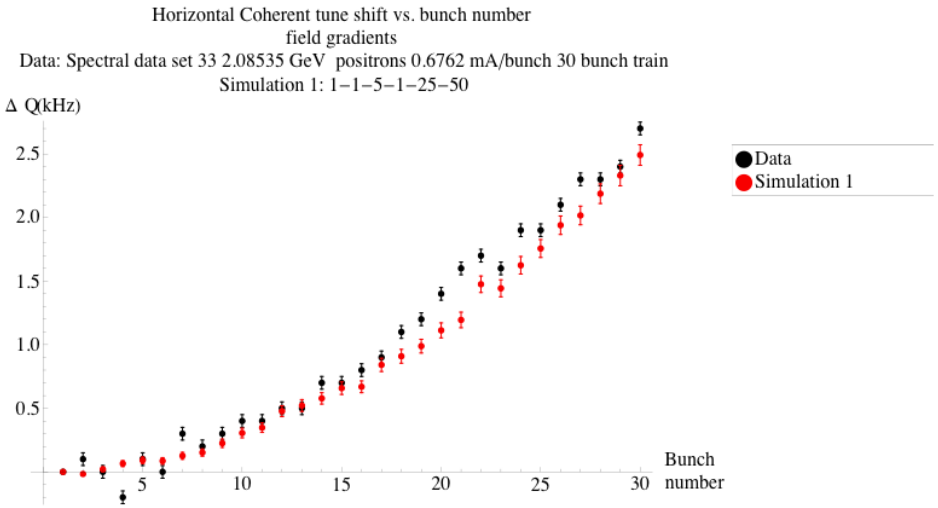
Conclusions

- 1st bunch in the train can exhibit head-tail (HT) line (m=-1 only)
  - Presence of "precursor" bunch eliminates its m=-1 signal of 1st bunch
  - Also leads to onset of HT lines at later bunch in train
    - Implies there is significant cloud density near beam lasting ≥ a few μsec
    - RFA measurements & simulations indicate possible "trapped" cloud in quadrupoles and wigglers
- Strong dependence of HT line structure observed
  - For last bunch in 30 positron bunch train
  - As function of the current in that bunch
- Electron trains
  - In identical conditions, HT lines also appear
  - Onset is later in the train; develops more slowly than for positrons
- Initial measurements of damping rates of single bunches in 30 bunch train. Future => "Effective electron cloud impedance"
- Both sets of measurements: Need more checks for systematics

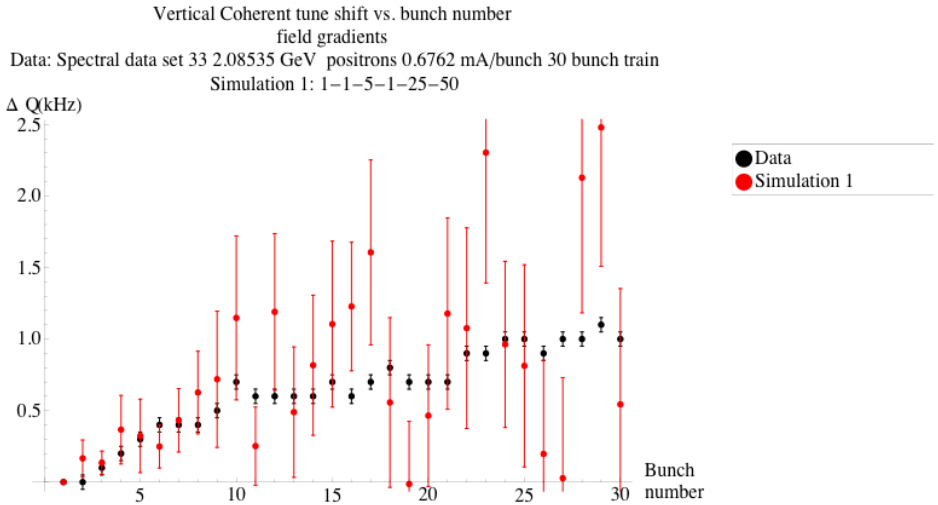
- Backup slides

Horizontal and Vertical Tunes: Simulation

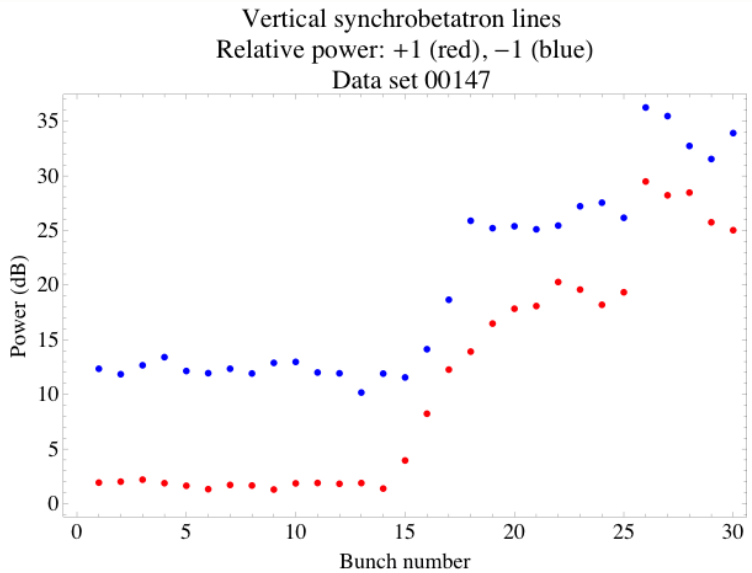


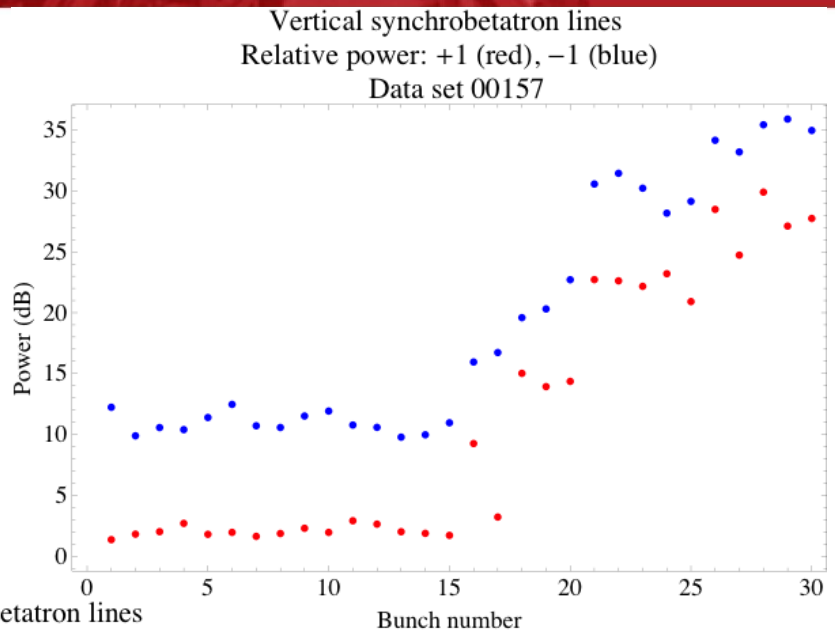


This POSINST simulation was done for a slightly different data set. The standard set of cloud model parameters, validated in previous tune shift studies, was used. Tunes were computed from field gradients. (Vertical gradients need better macro-particle statistics).

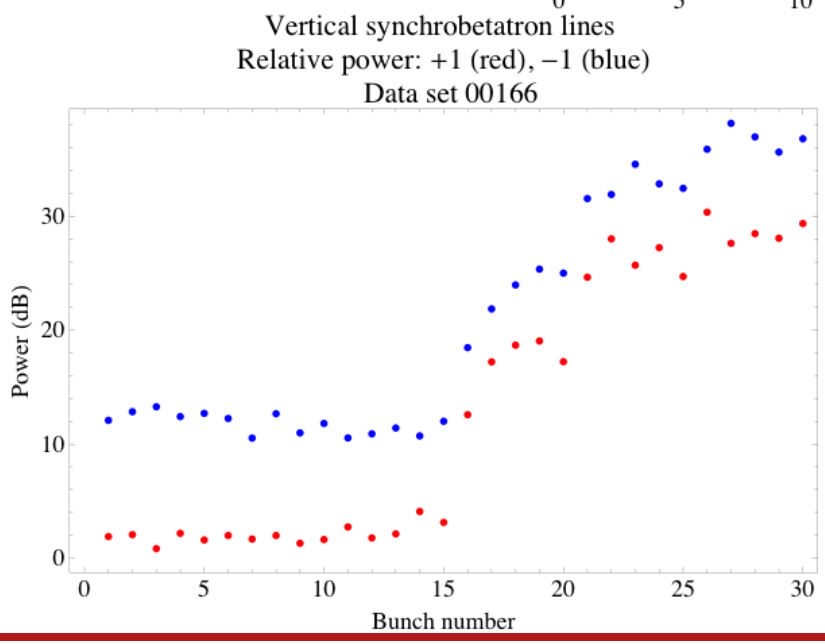


Study of Repeatibility of H-T Lines

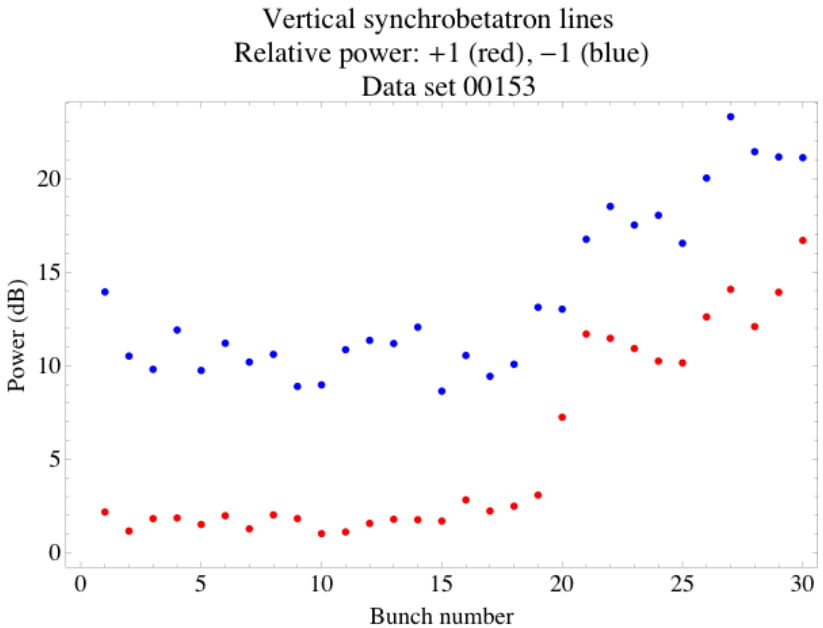




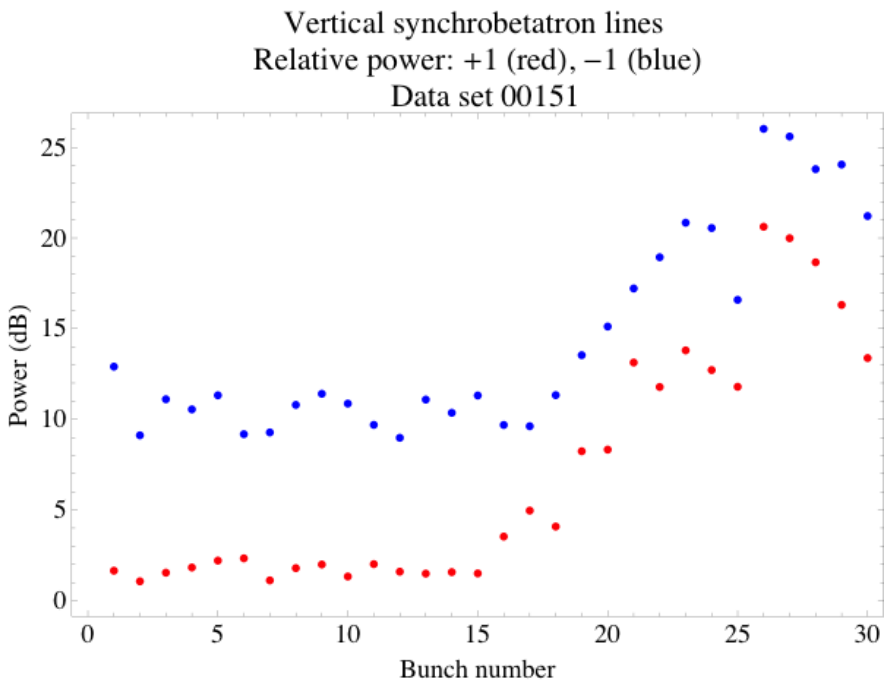
These 3 runs (147, 157, 166), performed at different times under nominally the same conditions, show the level of reproducibility of the observations.



Precursor Bunch Dependence II

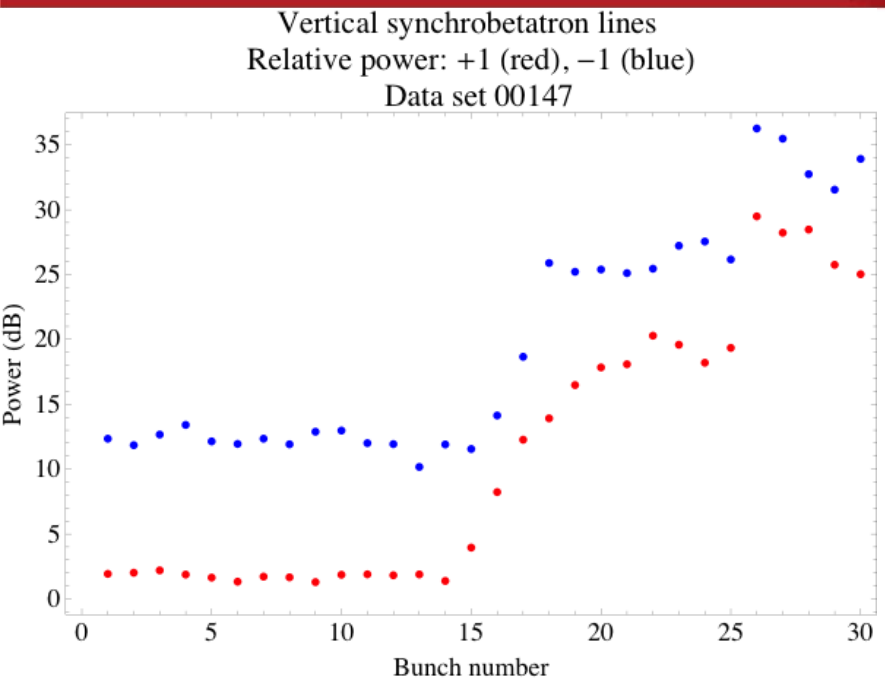


Run 153: precursor bunch 182 ns before bunch 1
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch = 0.736 mA
Bunch length = 12.8 mm



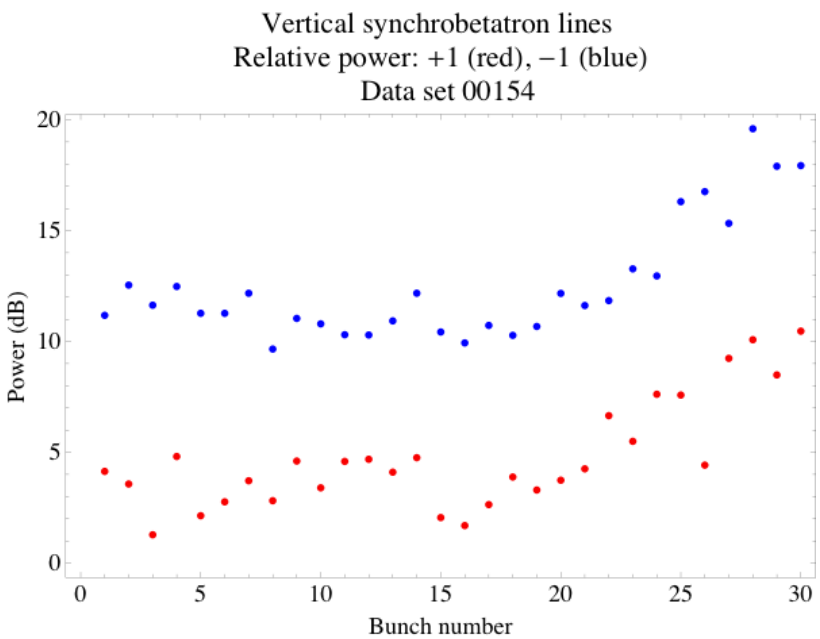
Run 151: no precursor
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch = 0.735 mA
Bunch length = 12.8 mm

Species Dependence



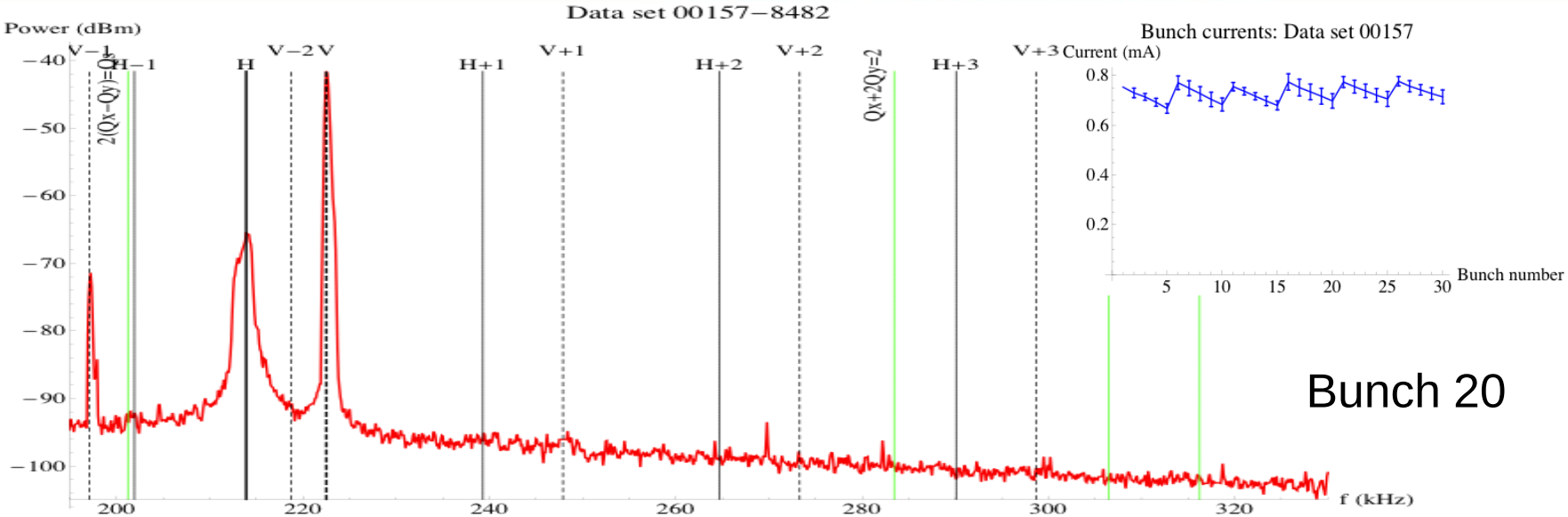
Run 147
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch = 0.735 mA
Positrons

Run 154
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch = 0.735 mA
Electrons

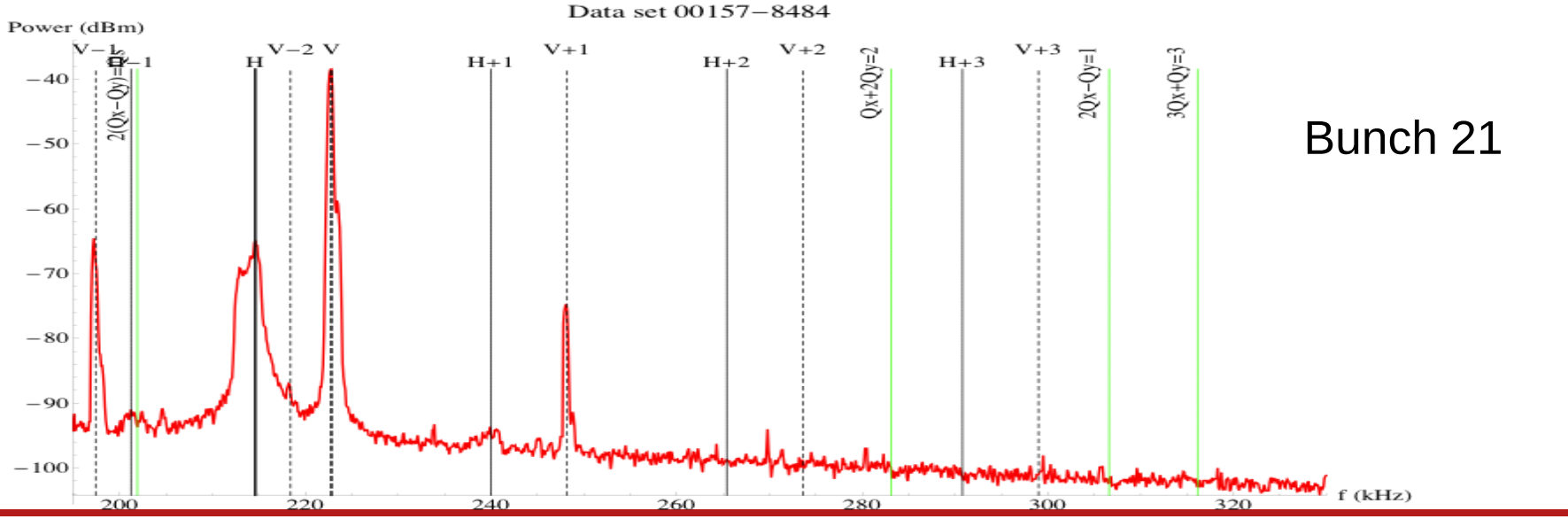


Ringwide avg vacuum ~0.6 nTorr

HT m = +1 Line Appearance at Bunch 21

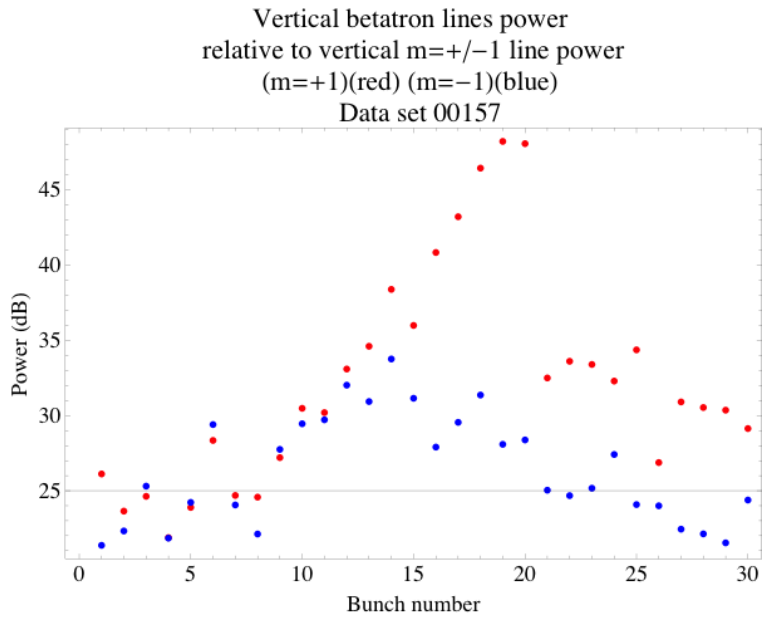


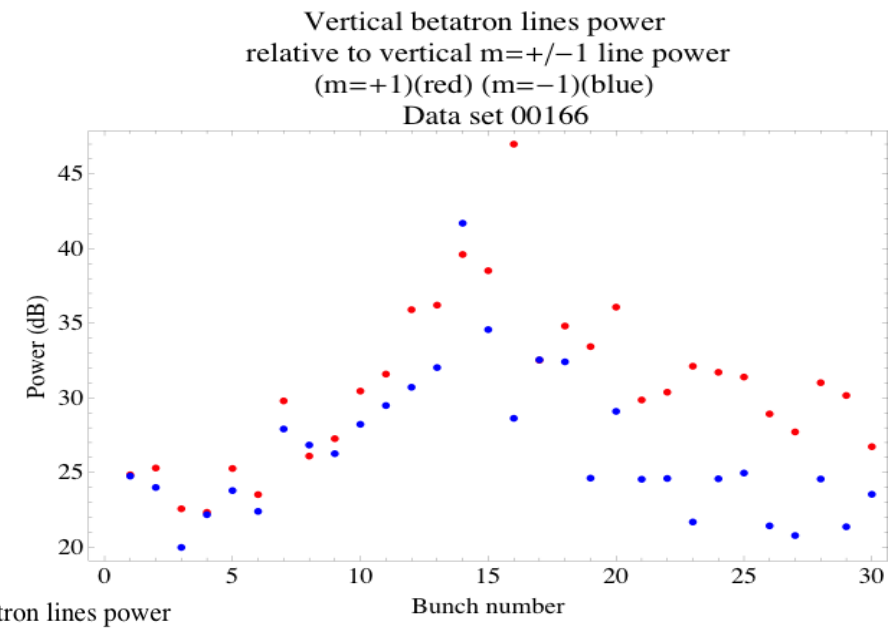
Bunch 20



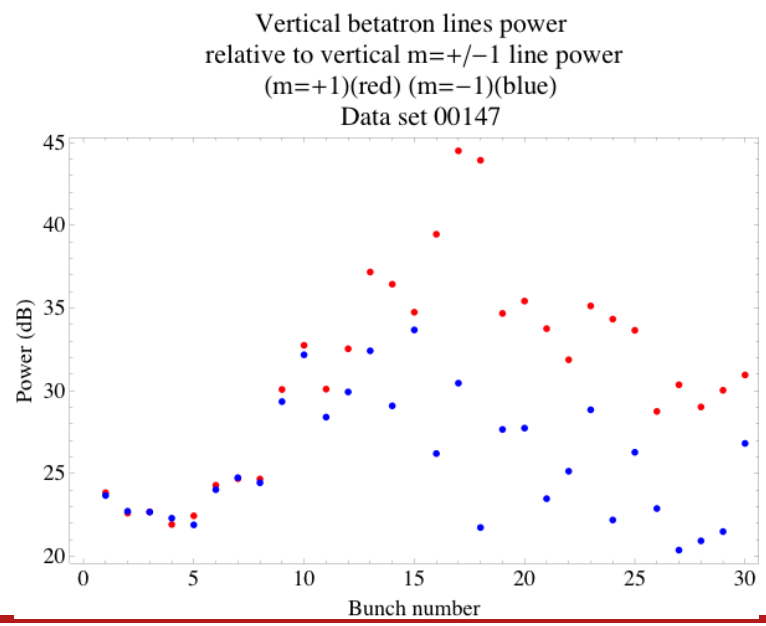
Bunch 21

Ratio of Betatron Power to HT-line Power (Vertical)

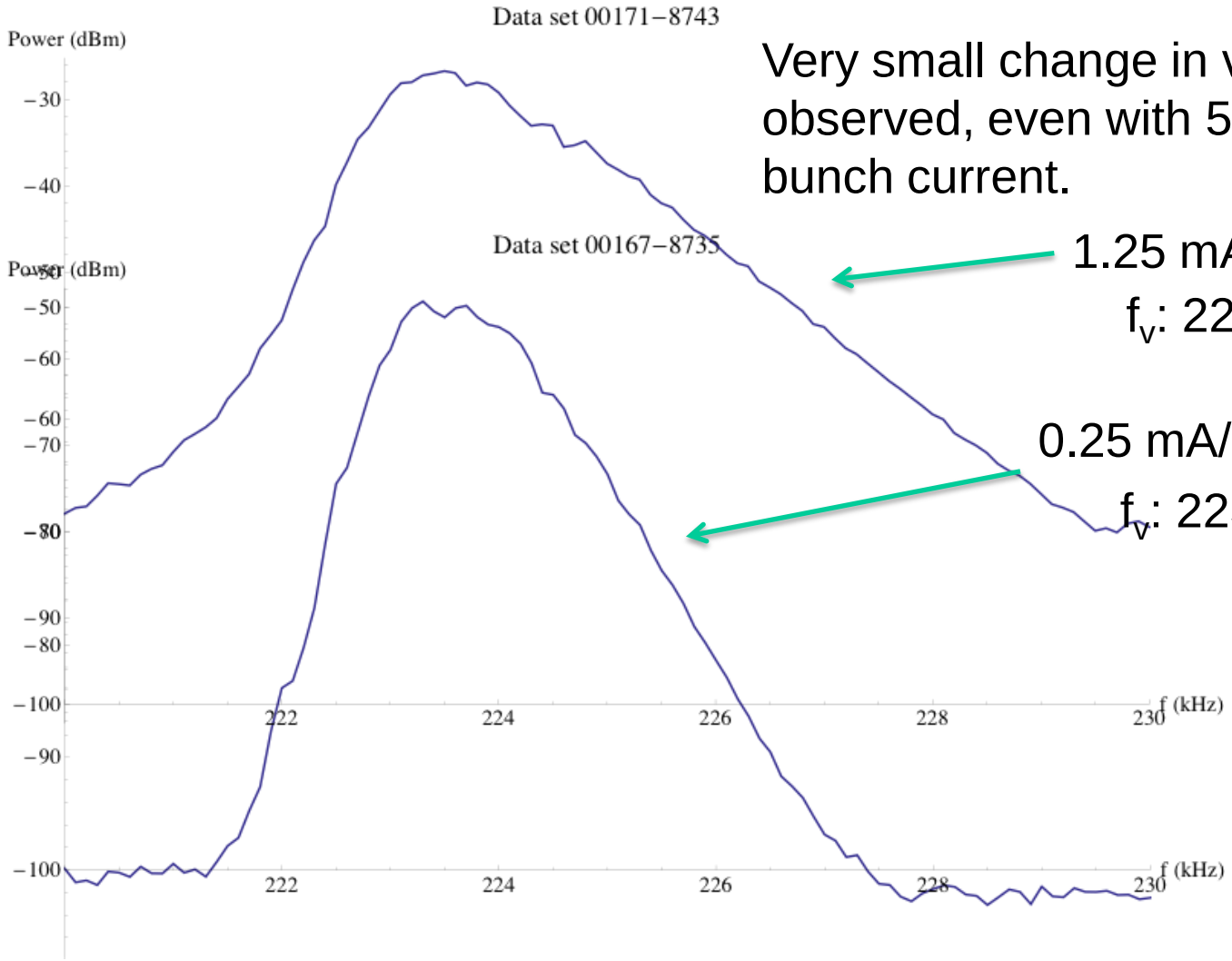




Runs 147, 157, 166 are shown. These were performed at different times under nominally the same conditions.



Vertical Betatron Line for Bunch 30: 0.25 mA Bunch vs 1.25 mA Bunch



Very small change in vertical tune observed, even with 5x change in bunch current.

1.25 mA/bunch
f_v: 223.5 kHz

0.25 mA/bunch
f_v: 223.3 kHz

EC-Induced Emittance Growth with Strong Feedback for Coupled-bunch Dipole Modes

- Measure Bunch-by-Bunch Beam Size
  - Beam size enhanced at head and tail of train
    Source of blow-up at head appears to be due to a long lifetime component of the cloud.
    Bunch lifetime of smallest bunches consistent with observed single bunch lifetimes during LET (Touschek-limited) and with relative bunch sizes.
  - Beam size measured around bunch 5 corresponds to $\varepsilon_y \sim$ 20pm-rad [σ_y=11.0±0.2 μm, β_{source}=5.8m]