Cesr-TA EC-Induced Beam Dynamics

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ECLOUD'10 WORKSHOP

10/10/10

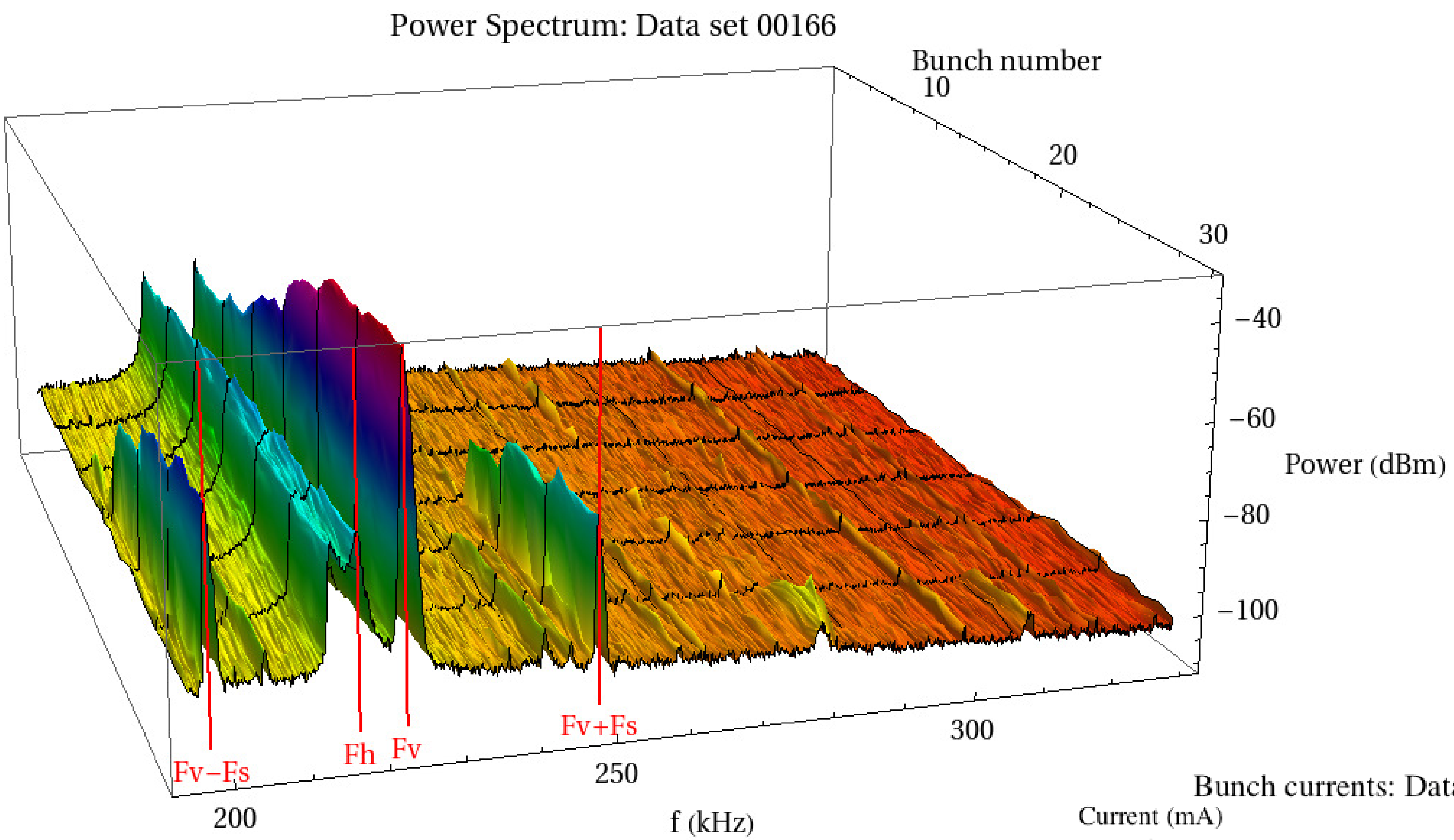
EC-induced beam dynamics work-I

- To continue our studies of electron cloud related phenomena, we have been developing the capability to make automated measurements of frequency spectra of individual bunches, from a single button BPM, to look for signals for single-bunch instabilities.
- In this mode, a button BPM at 33W (sensitive to both vertical and horizontal motion) is gated on a single bunch, and the signal is routed to a spectrum analyzer.
- For each bunch in the train, frequency spectra spanning the range from about 170 to 330 kHz are taken automatically (10 s average). (Revolution frequency is 390 kHz; lowest betatron sidebands are at about 212 kHz horizontal and 225 kHz vertical. Synchrotron frequency is about 25 kHz).
- Machine conditions, such as bunch current, magnet settings, feedback system parameters, etc. are automatically recorded and stored before and after each single-bunch spectrum is taken.

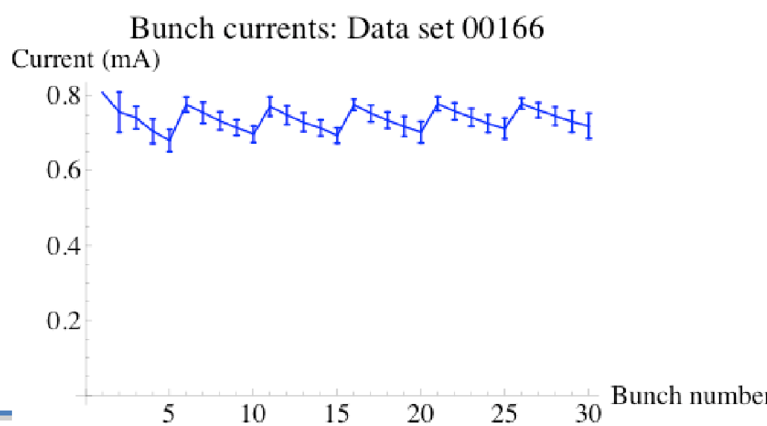
- Using this system during the recent July-August and September runs, a number of experiments which illuminate the dynamics of the electron-cloud/beam interaction at CesrTA. This talk will review results from these experiments.
- All experiments were done at 2.1 GeV in a low emittance lattice: nominal vertical emittance 20 pm, bunch length 10.8 mm, horizontal emittance 2.6 nm, tunes H 14.57, V 9.6, S 0.065, mom comp. 6.8×10^{-3}
- Trains with bunch numbers from 30-45, and bunch currents in the range of 0.5-1 mA (0.8-1.6 x 10^{10} per bunch) were studied.
- Systematic checks were made to rule out intermodulation distortion in the BPM electronics.
- It was checked that the betatron and head-tail lines moved as expected when the vertical, horizontal, and synchrotron tunes were varied.
- The longitudinal feedback was off for these measurements. The vertical and horizontal feedback were turned down, but not fully off. Normal settings are -2000 for each; experiments were done with the feedback at -400. Some experiments explored the effect of turning the vertical feedback off.

- The basic observation is that, under a variety of conditions, the frequency spectra exhibit the vertical m=+/- 1 head-tail lines, separated from the vertical betatron line by the synchrotron frequency, for some of the bunches during the train. The amplitude of these lines typically (but not always) grows along the train.
- Typically, for the bunch at which the vertical head-tail lines first appear above the noise floor (about 40 db below the vertical betatron line), we first observe growth in the beam size, which continues to increase along the train. (see later talk by John Flanagan.)
- Under some conditions, the first bunch in the train also exhibits a head-tail line (m=-1 only). The presence of a "precursor" bunch ("clearing" bunch) eliminates the m=-1 signal in the first bunch.
- Subsequent slides in this talk will present the details of these observations, together with their dependence on machine and beam parameters such as current, number of bunches, chromaticity, synchrotron tune, etc.

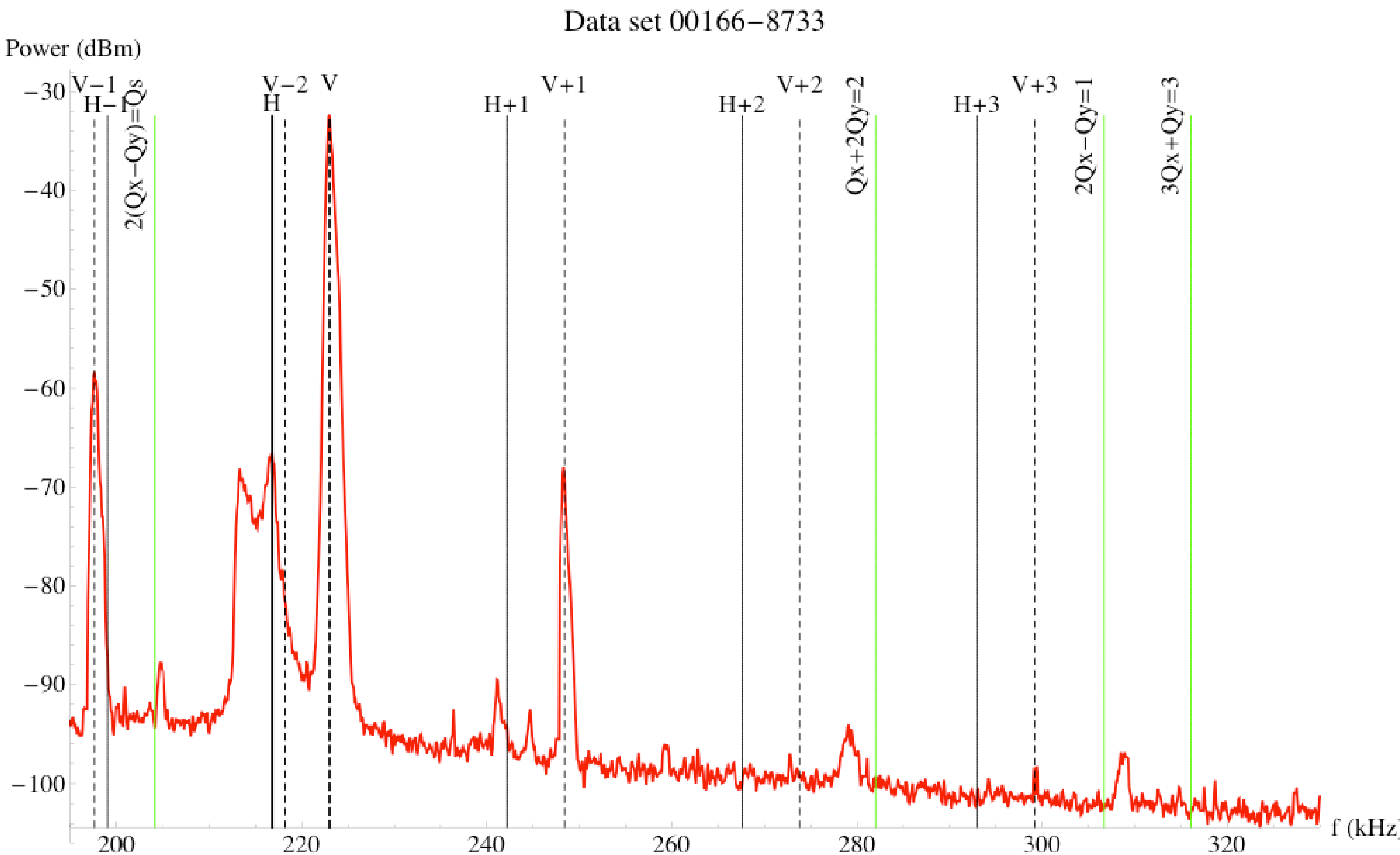
Bunch-by-bunch power spectrum Run 166



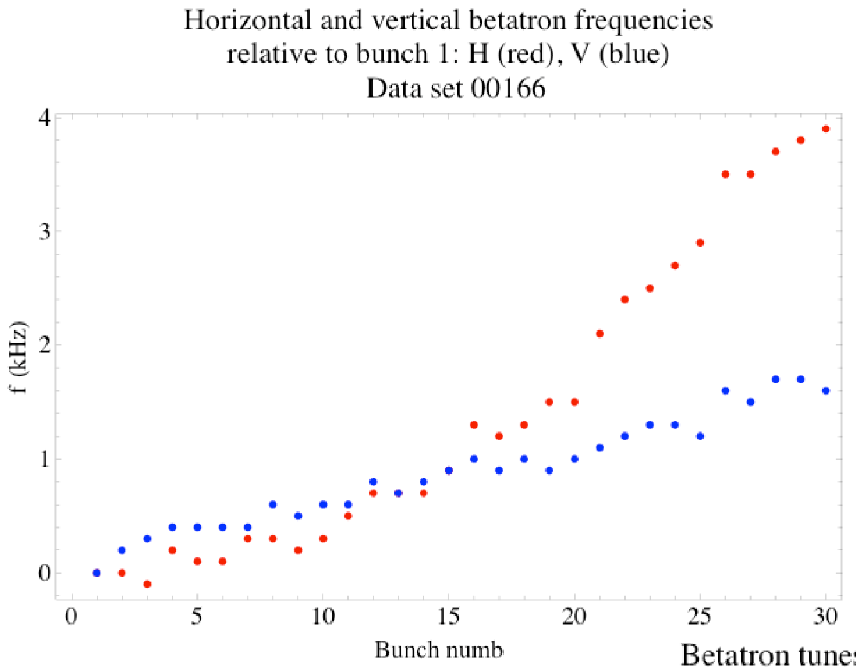
(H,V) chrom = (1.33,1.155)
Avg current/bunch 0.74 mA.

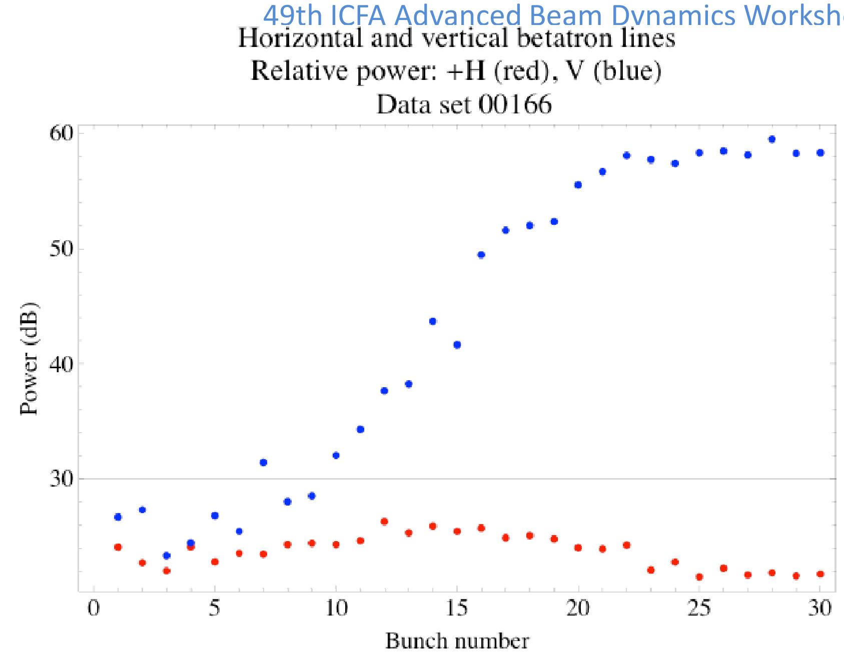


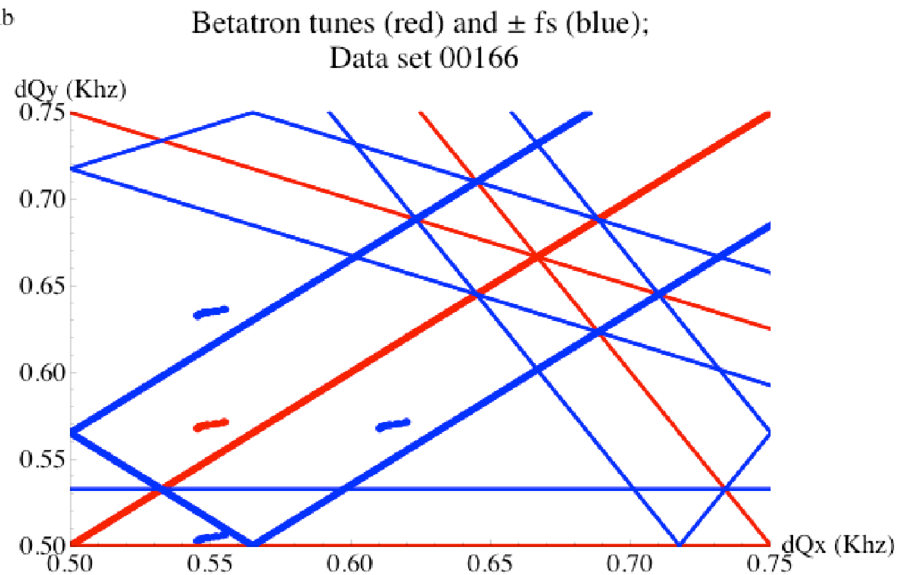
Detail of spectrum of bunch 30-run 166



Horizontal and vertical betatron lines

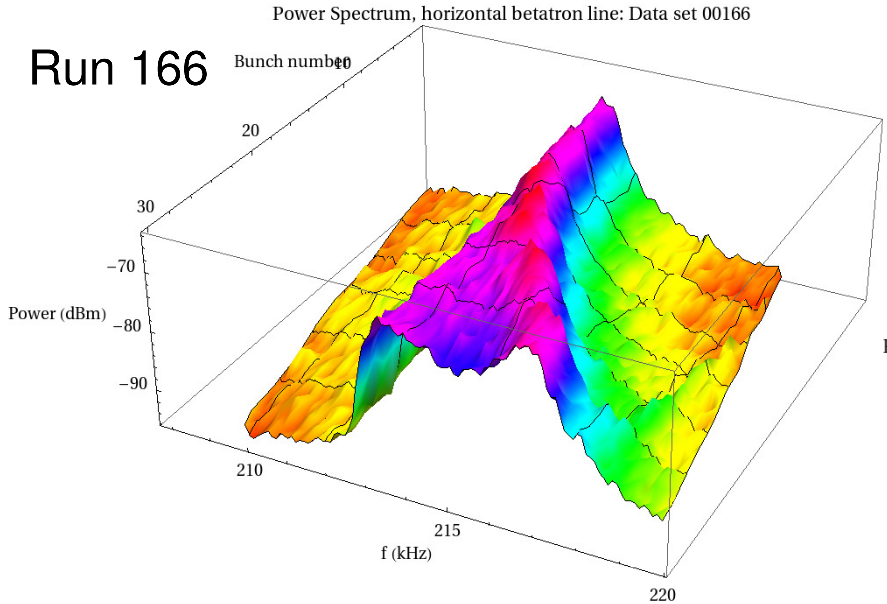




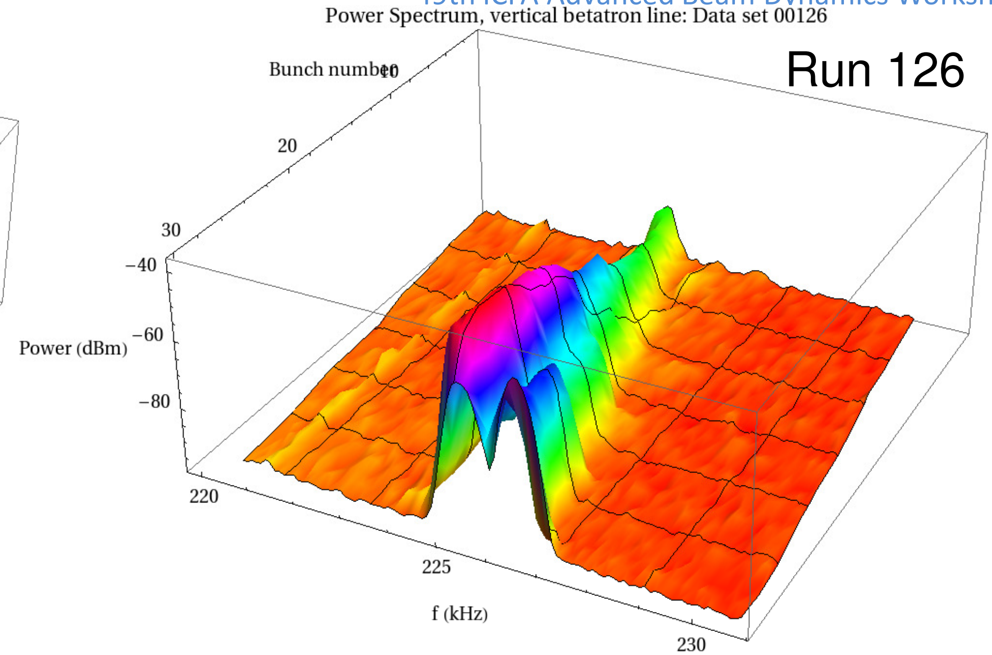


Detailed features of horizontal and vertical lines

Run 166



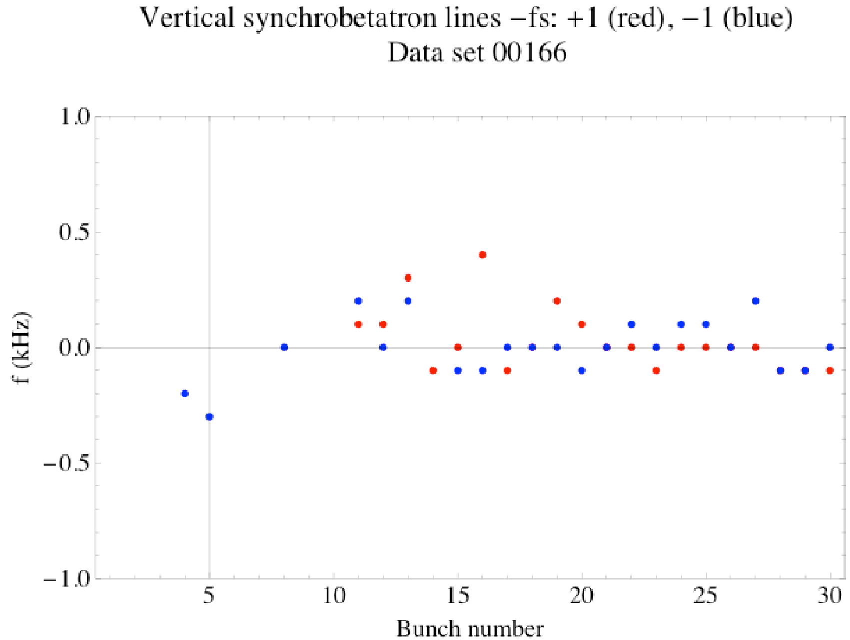
Run 126

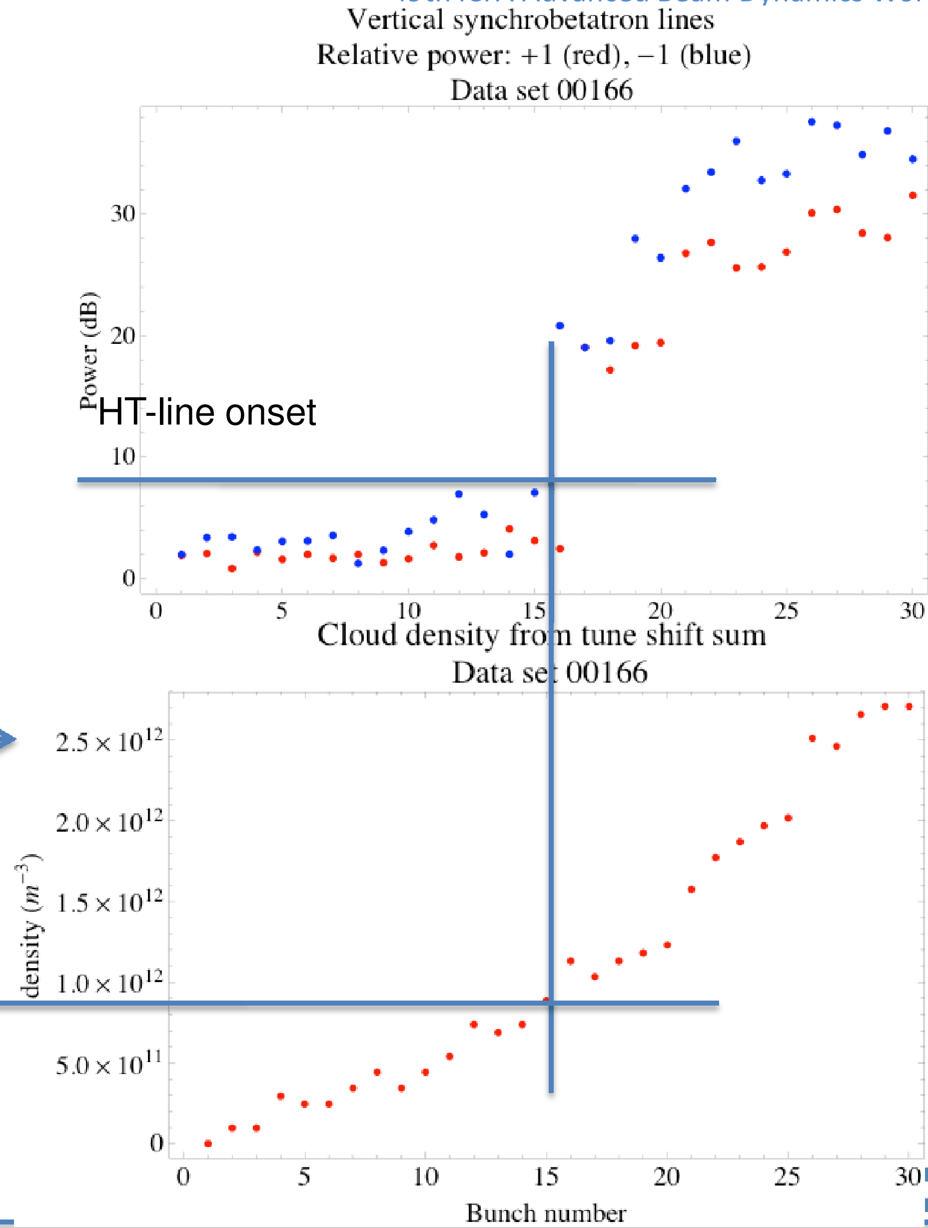


Lower frequency (~3 kHz) shoulder in the horizontal tune spectrum is attributable to known dependence of horizontal tune on the multibunch mode.

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 understood.

Vertical head-tail lines; correlation with cloud density

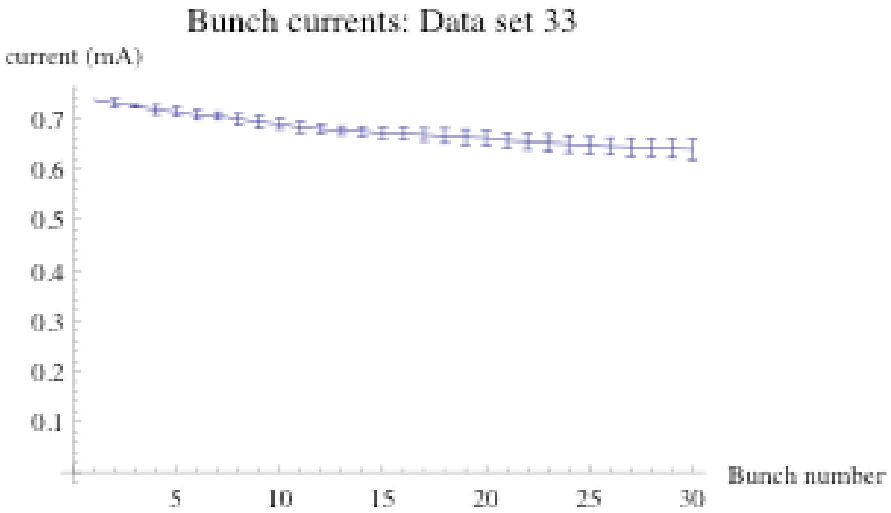


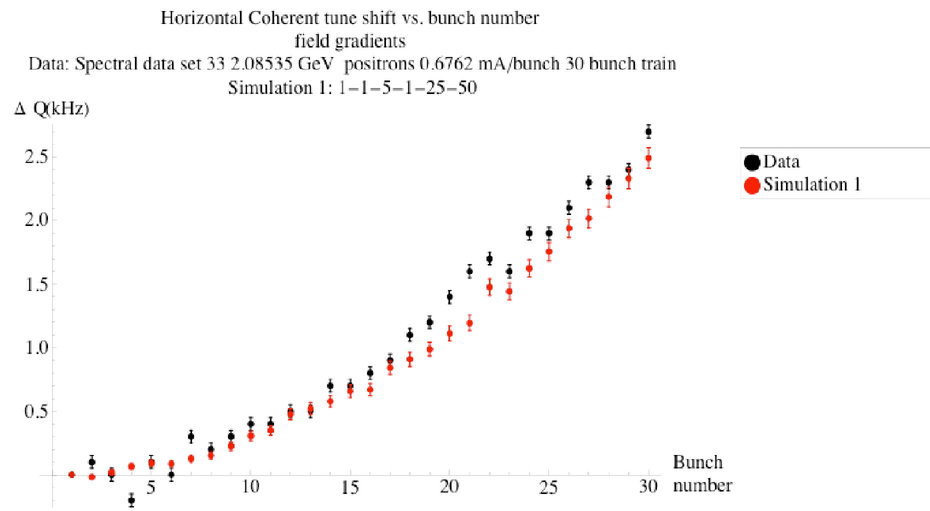


From tune shift data. Assumes 474 m of dipoles, equal vertical and horizontal β= 16 m.

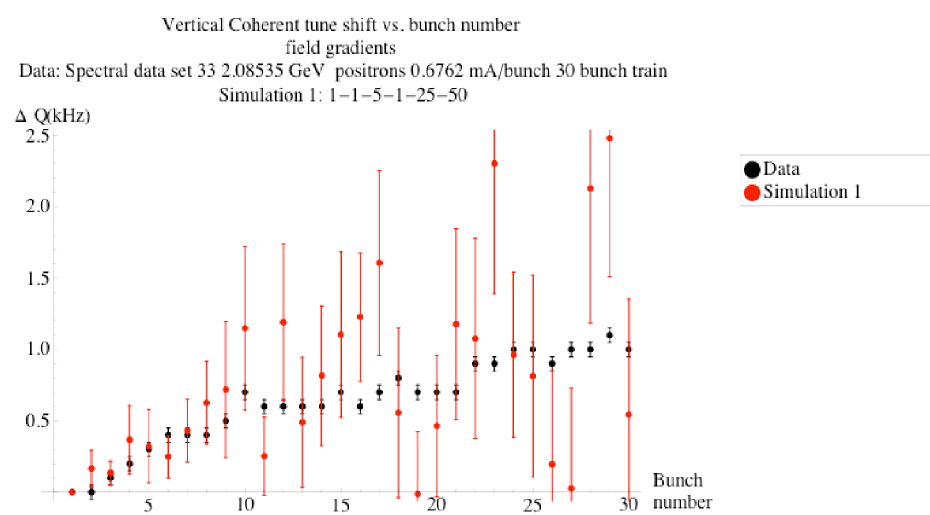
Cloud density at HT-line onset: ~8-9x10^{11}/m^3

Horizontal and vertical tunes-simulation



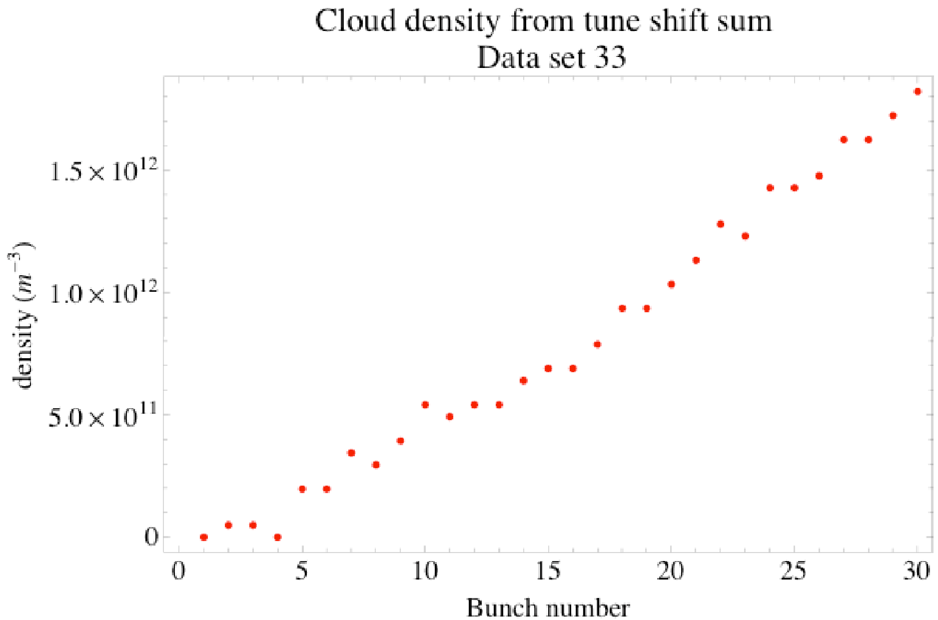


This POSINST simulation was done for a slightly different data set.
The standard set of cloud model parameters, validated in previous tune shift studies, was used.Tunes were computed from field gradients.
(Vertical gradients need better macroparticle statistics).

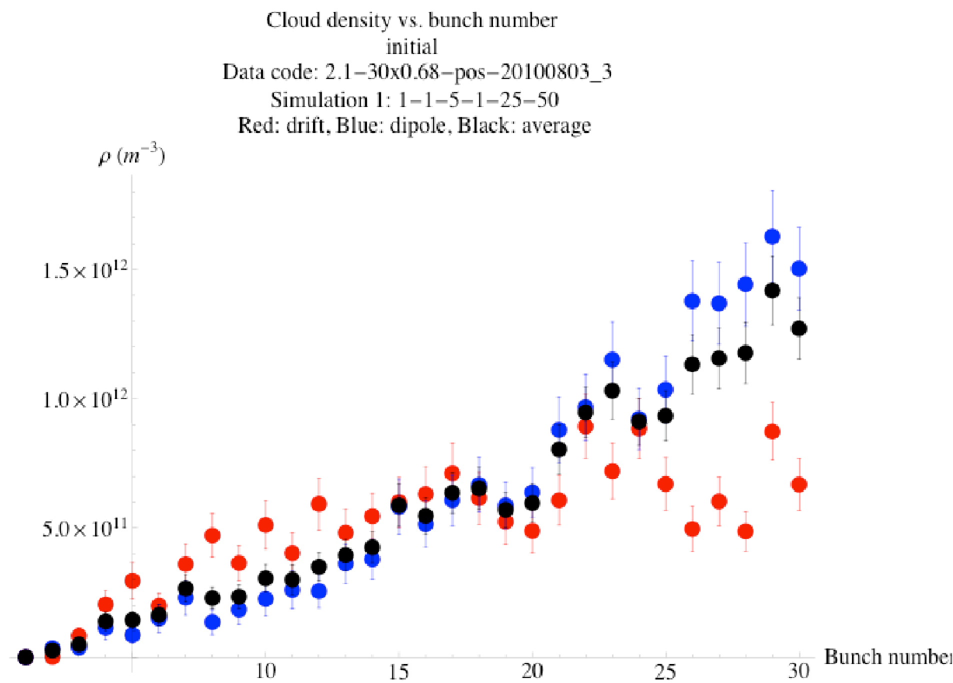


Cloud density comparisons

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

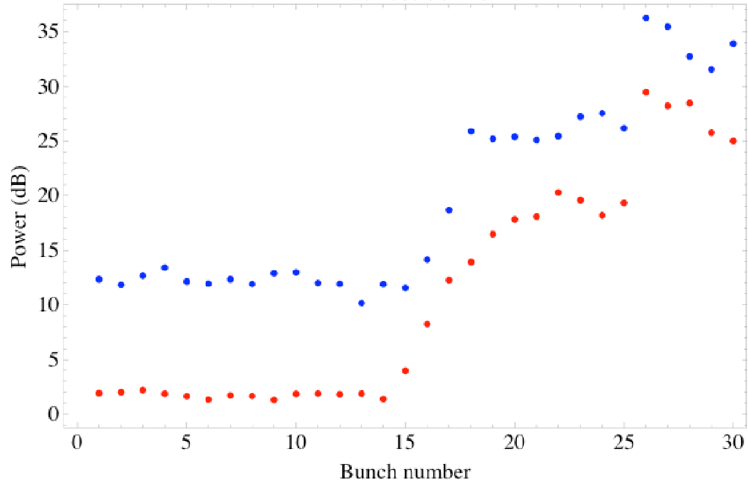


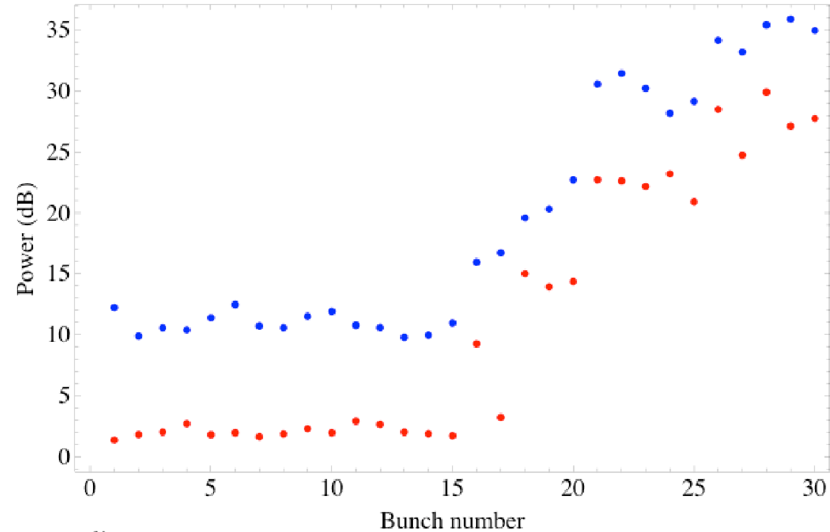
From simulation



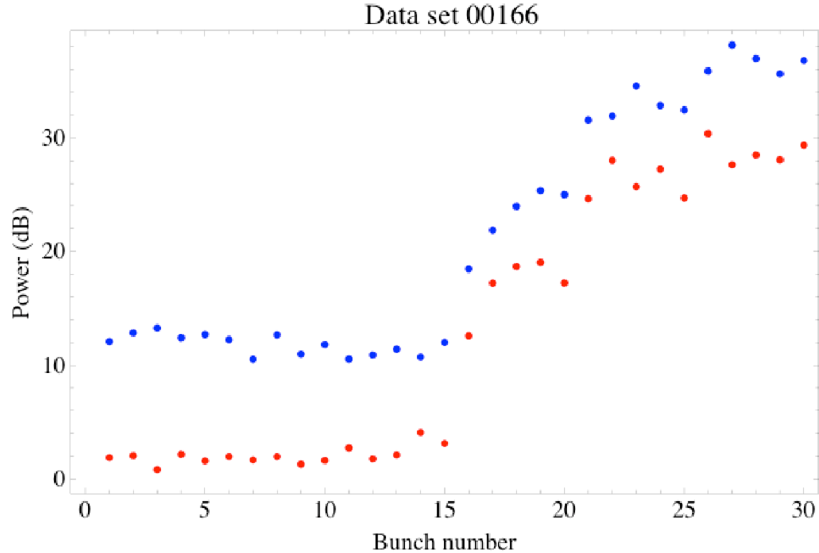
The cloud density computed directly (but approximately) from the tune shifts agree relatively well with that from a cloud simulation which reproduces the measured tune shifts.

Study of repeatability of H-T lines

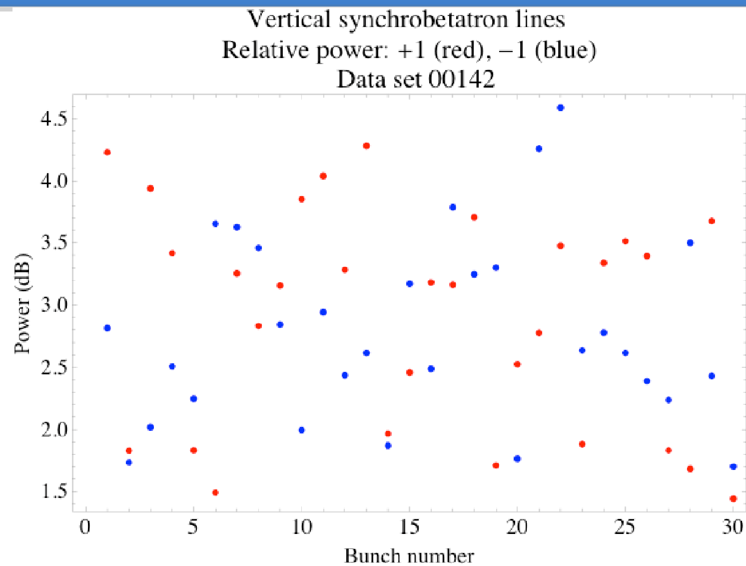




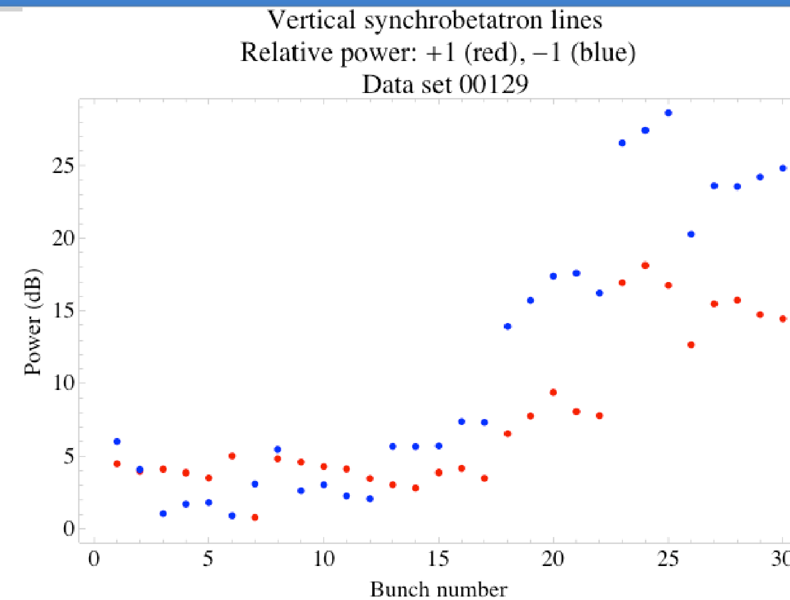
These 3 runs (147, 157, 166), performed at different times under nominally the same conditions, show the level of reproducilibity of the observations.



Study of vertical chromaticity dependence

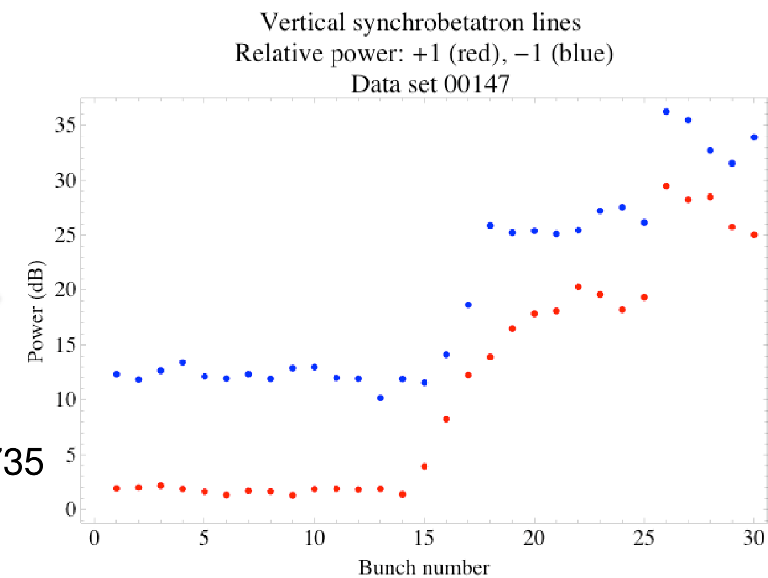


Run 142
V Chromaticity = 1.99
H Chromaticity = 1.34
Nominal current/bunch (mA) = 0.736

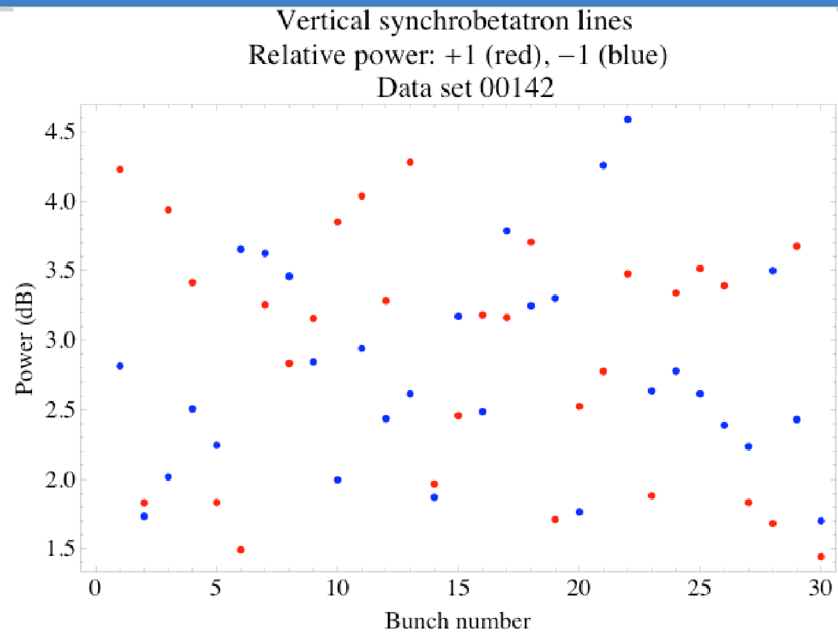


Run 129
V Chromaticity = 1.78
H Chromaticity = 1.07
Nominal current/bunch (mA) = 0.738

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

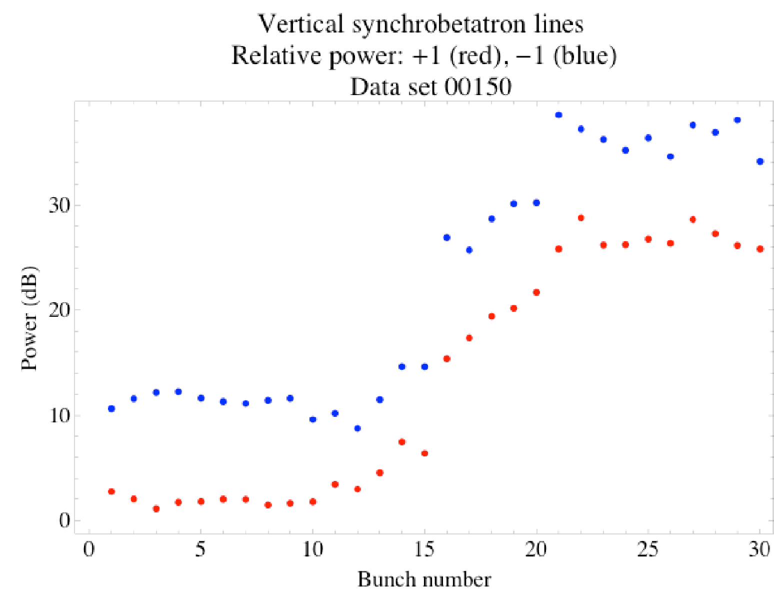


Study of current dependence-I

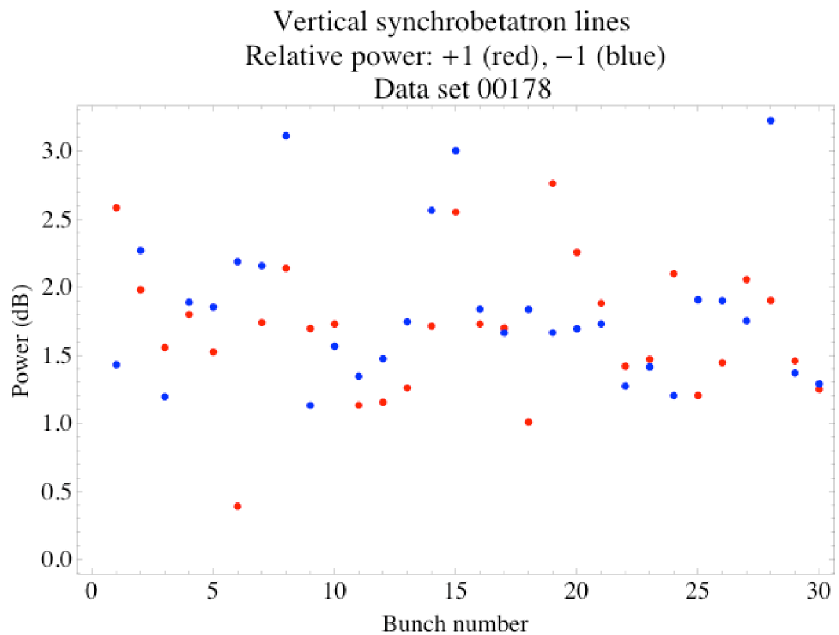


Run 142
V Chromaticity = 1.99
H Chromaticity = 1.34
Nominal current/bunch (mA) = 0.736

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

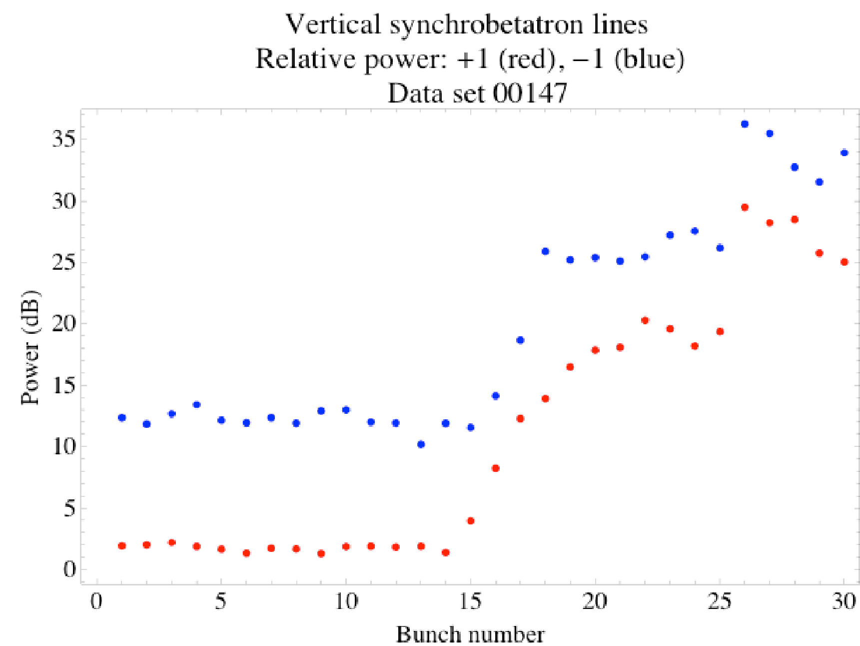


Study of current dependence-II

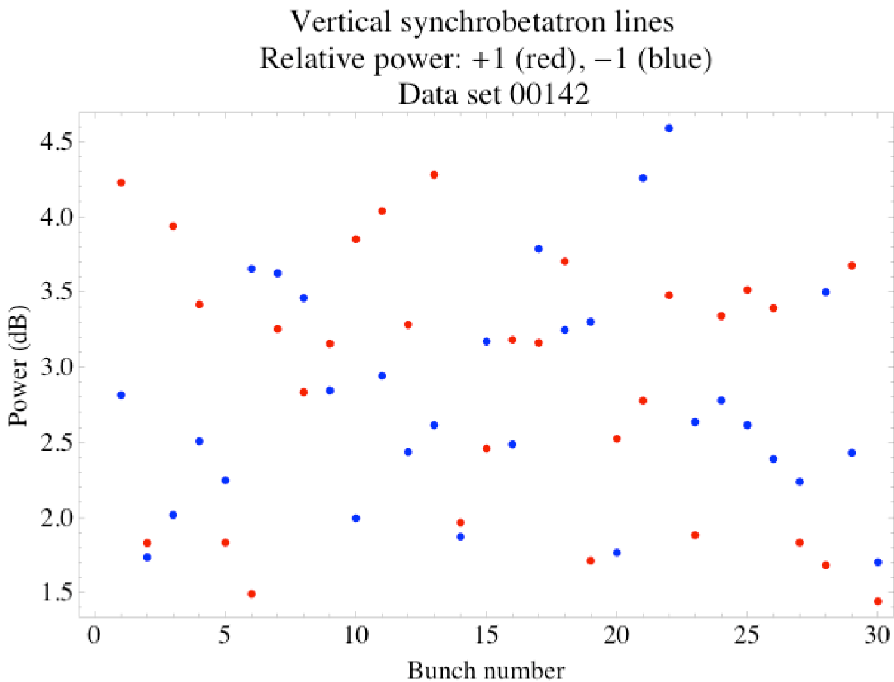


Run 178
V Chromaticity = 1.11
H Chromaticity = 1.34
Nominal current/bunch (mA) = 0.5

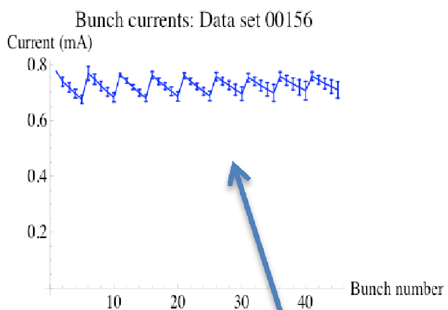
Run 147
V Chromaticity = 1.11
H Chromaticity = 1.34
Nominal current/bunch (mA) = 0.736



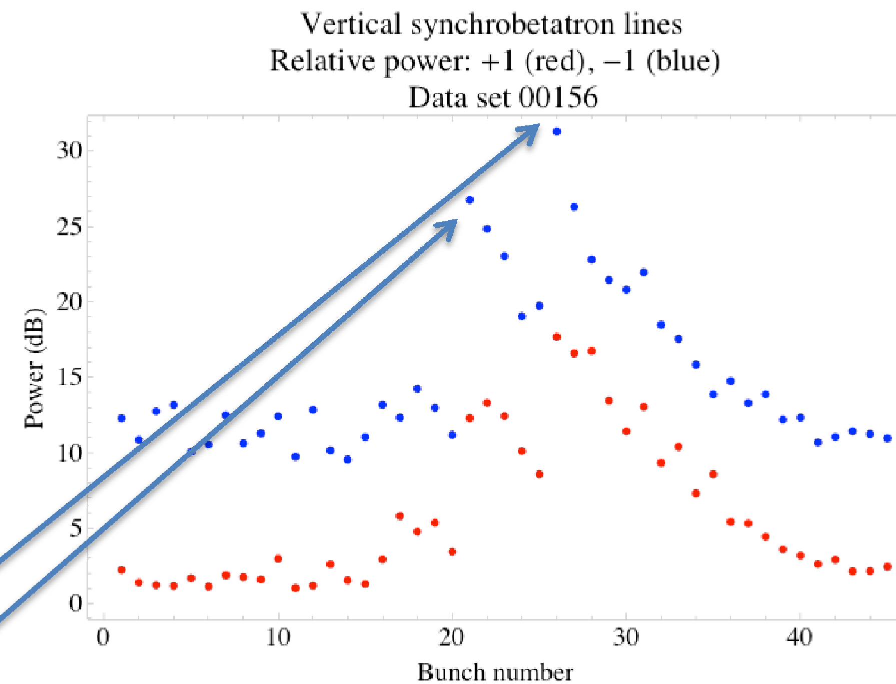
Bunch number dependence



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



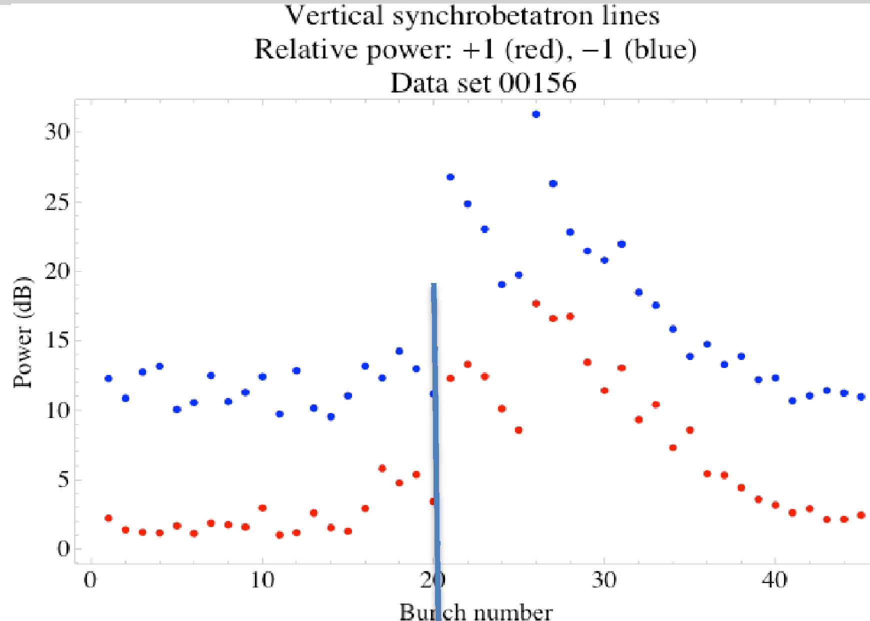
Run 156
V Chromaticity = 1.99
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.725
45 bunches



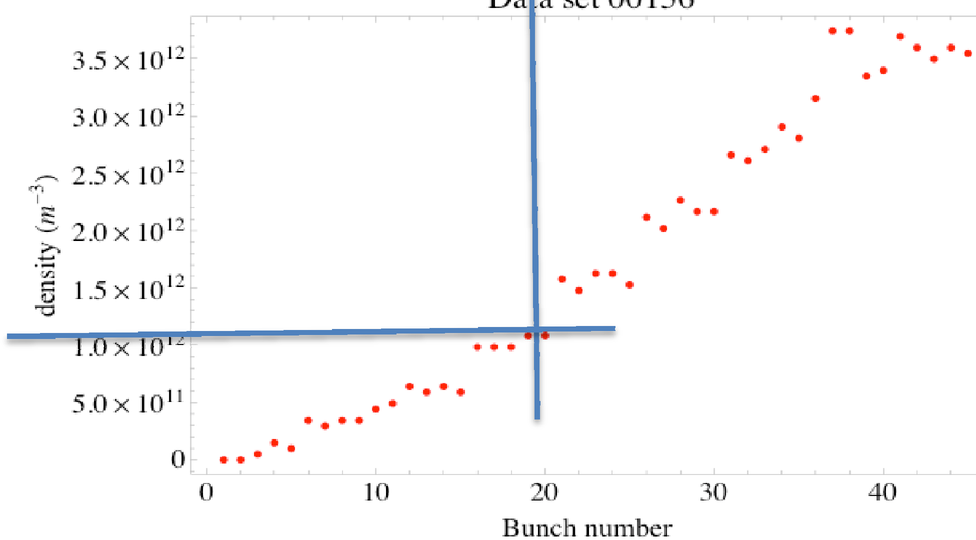
(increased amplitude at bunches 21 and 26 due to refilling of train at these bunch numbers)

HT line/cloud density correlation: 45 bunches

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

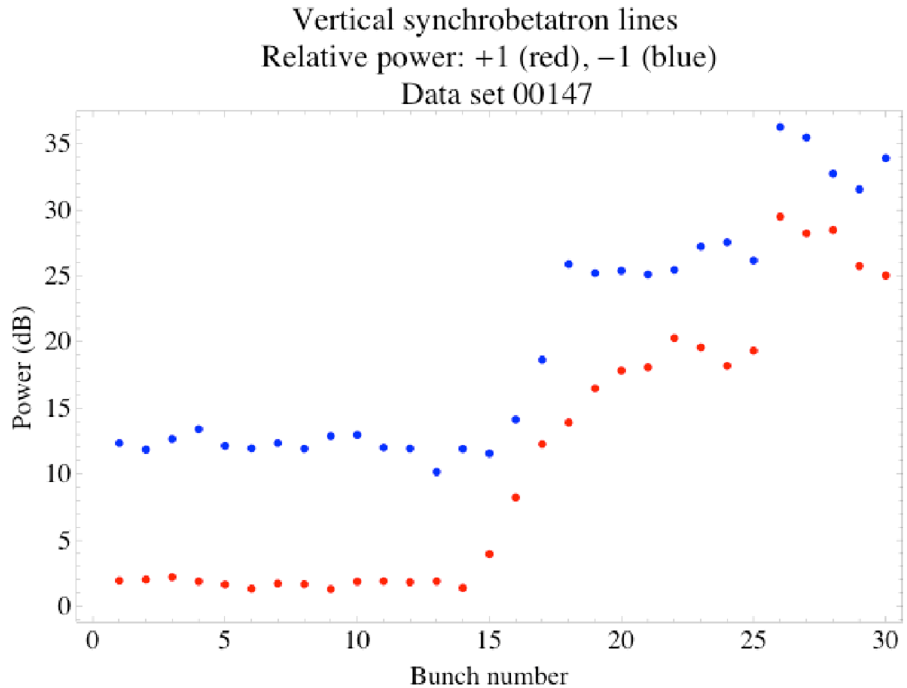


From tune shift data. Assumes 474 m of dipoles, equal vertical and horizontal β= 16 m.



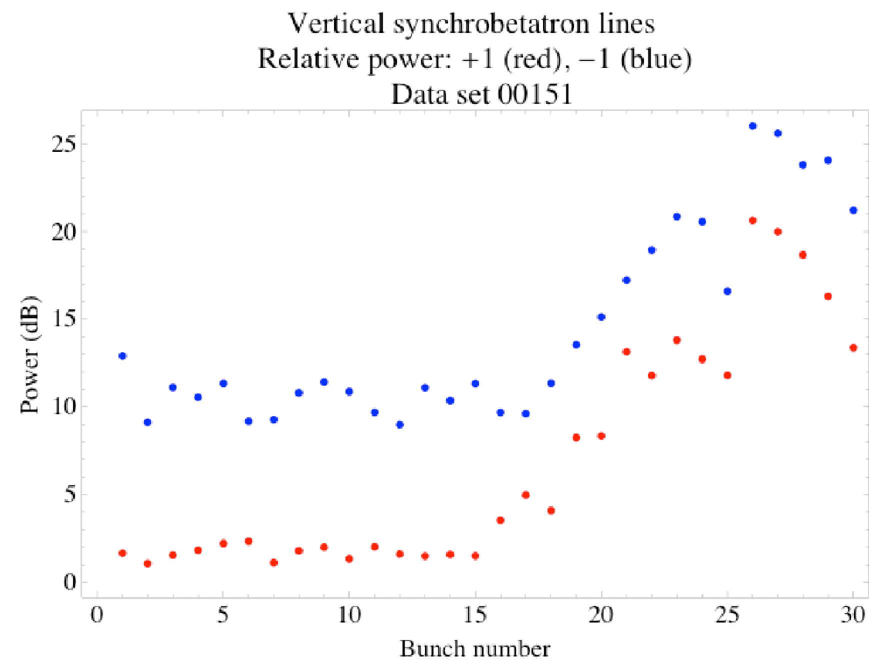
Onset of HT-lines: ~1.1×10^{12}/m^{-3}

Synchrotron tune dependence

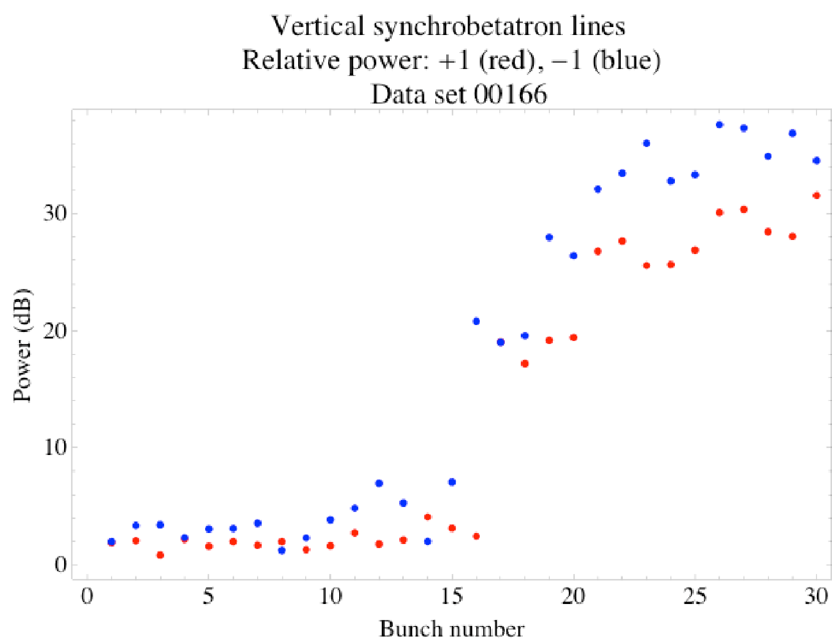


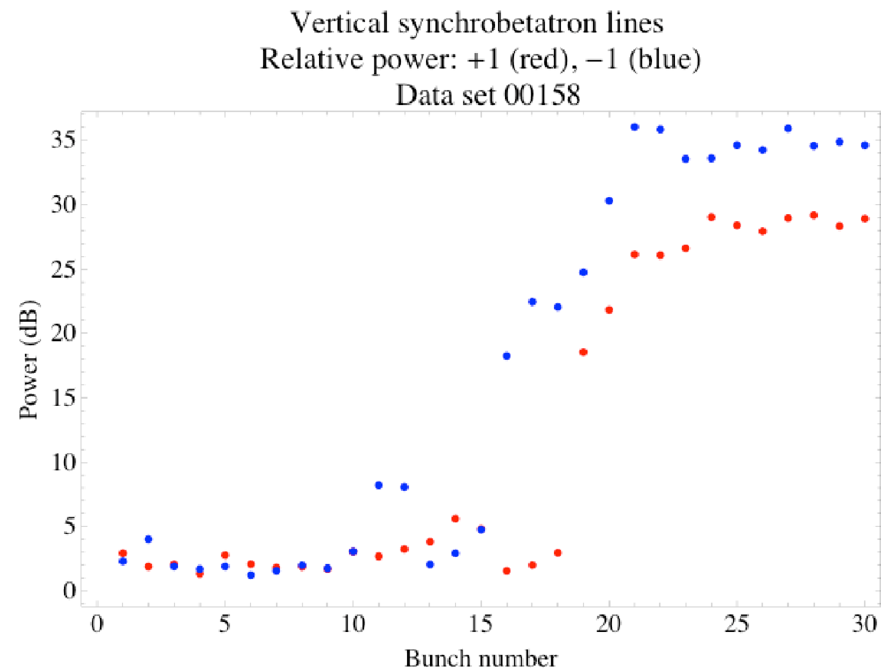
V Chromaticity = 1.15
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.735
Synch tune = 25.4 kHz
Bunch length = 10.5 mm

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



Vertical emittance dependence- 30 bunches

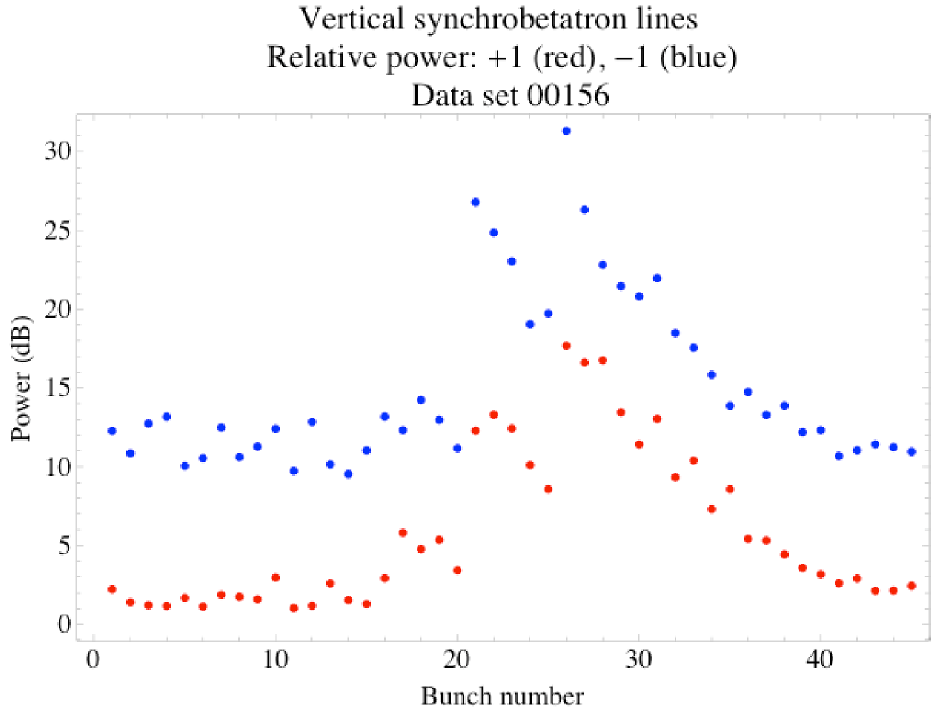


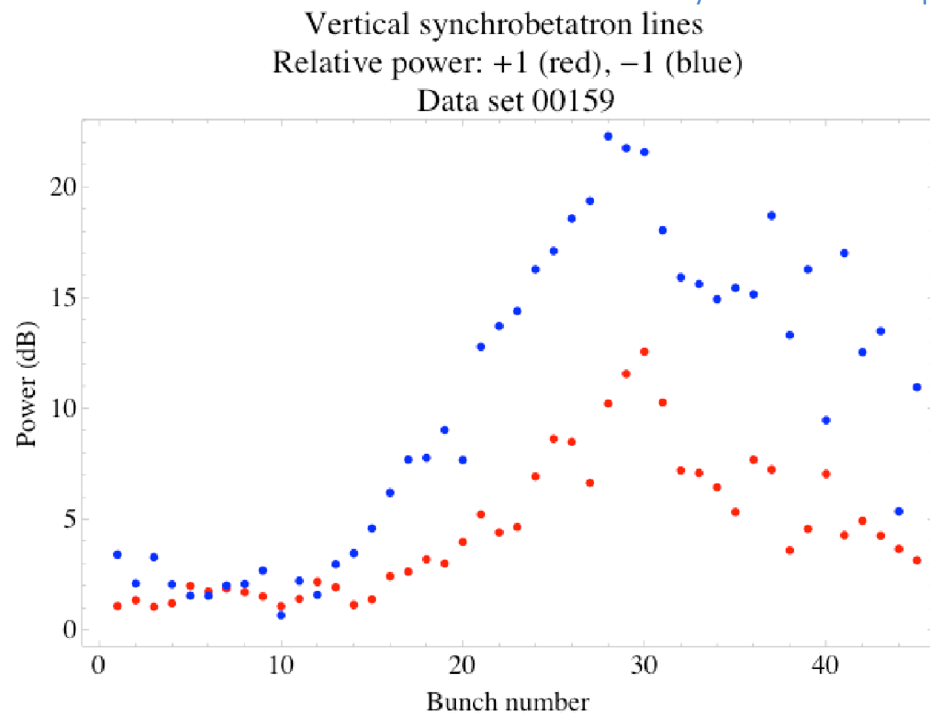


Run 166:
Low vertical emittance (~20 pm)
30 bunches

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

Vertical emitance dependence- 45 bunches

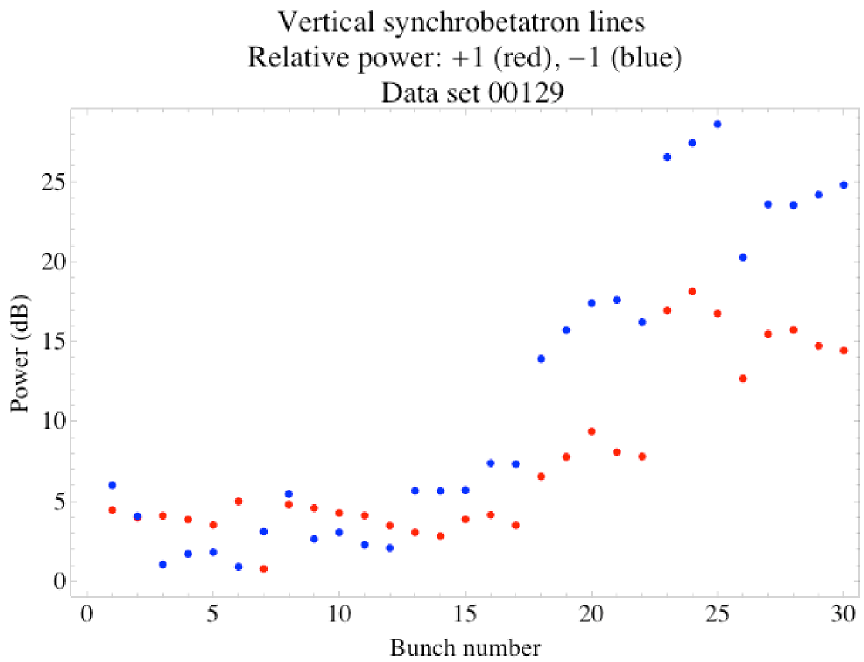


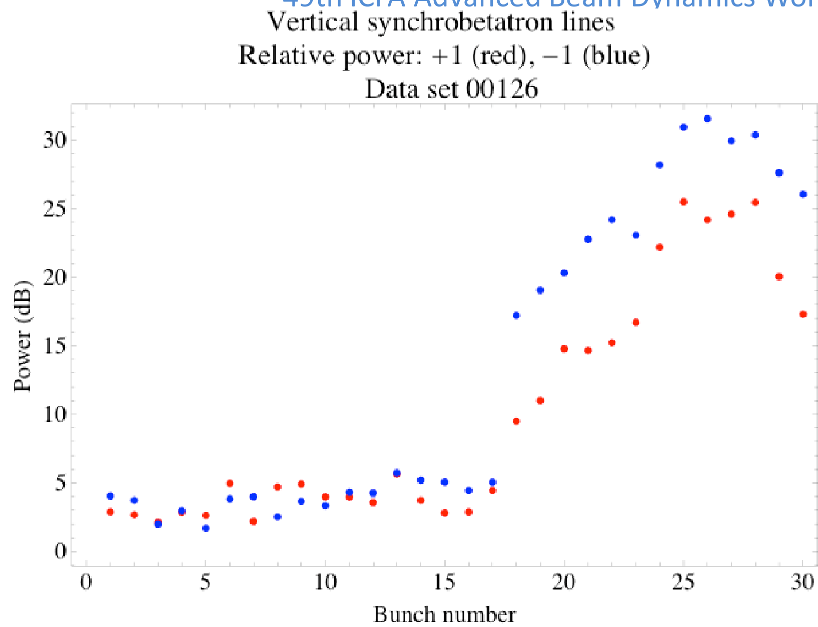


Run 156:
Low vertical emittance (~20 pm)

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

Vertical feeback dependence



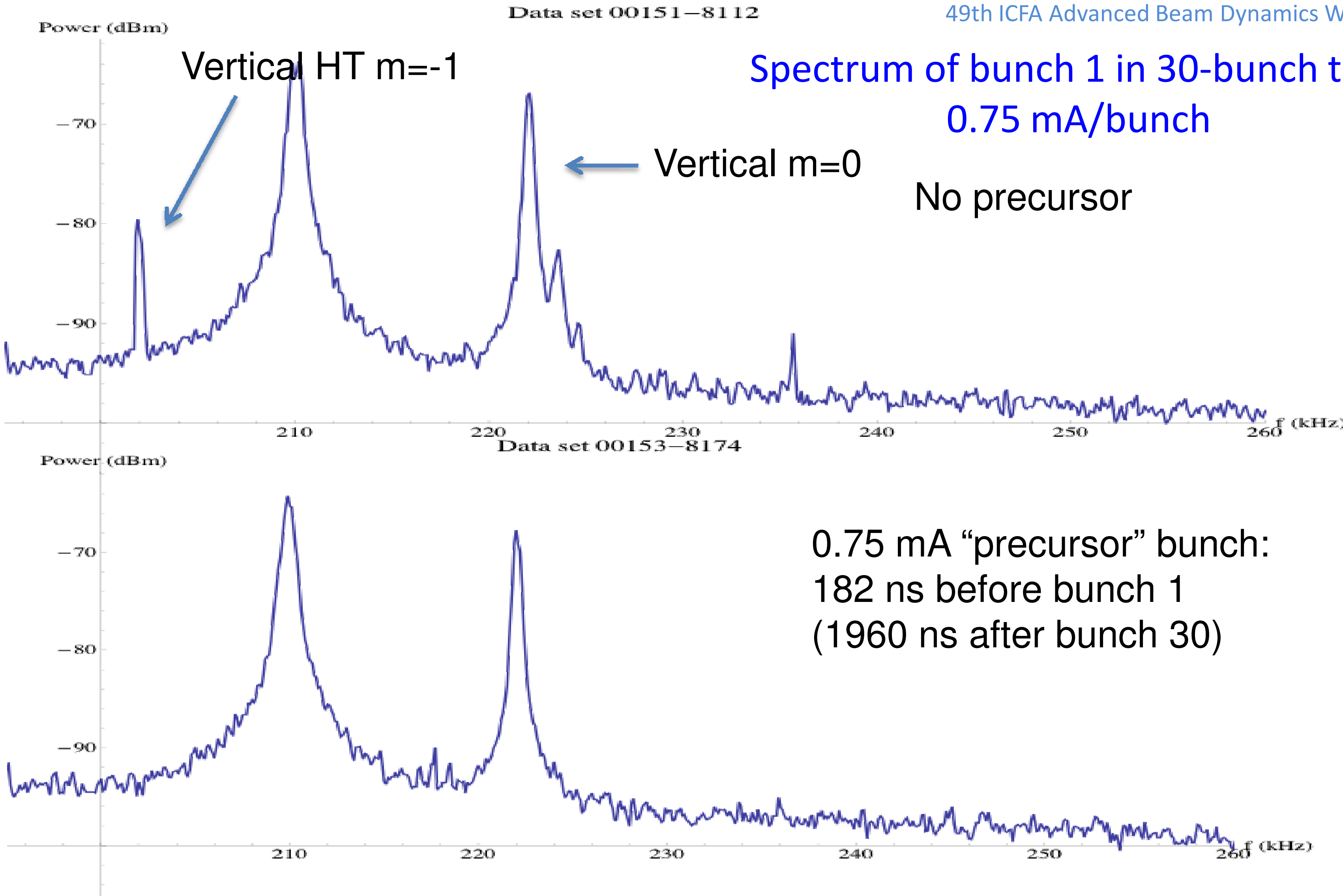


Run 129:
Positron feedback (H,V,L) = (-400, -400, 0)
Nominal current/bunch (mA) =0.738

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

Precursor bunch dependence

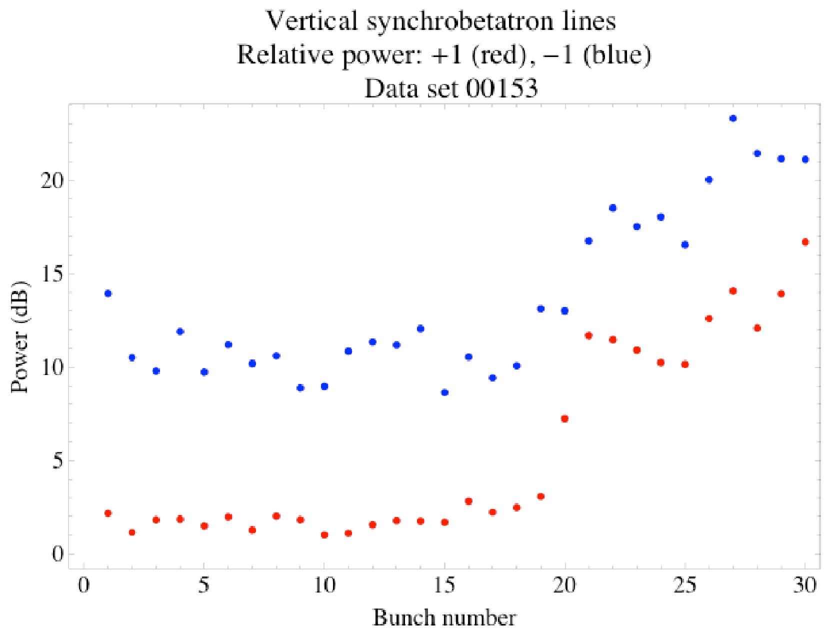
Spectrum of bunch 1 in 30-bunch train
0.75 mA/bunch



No precursor

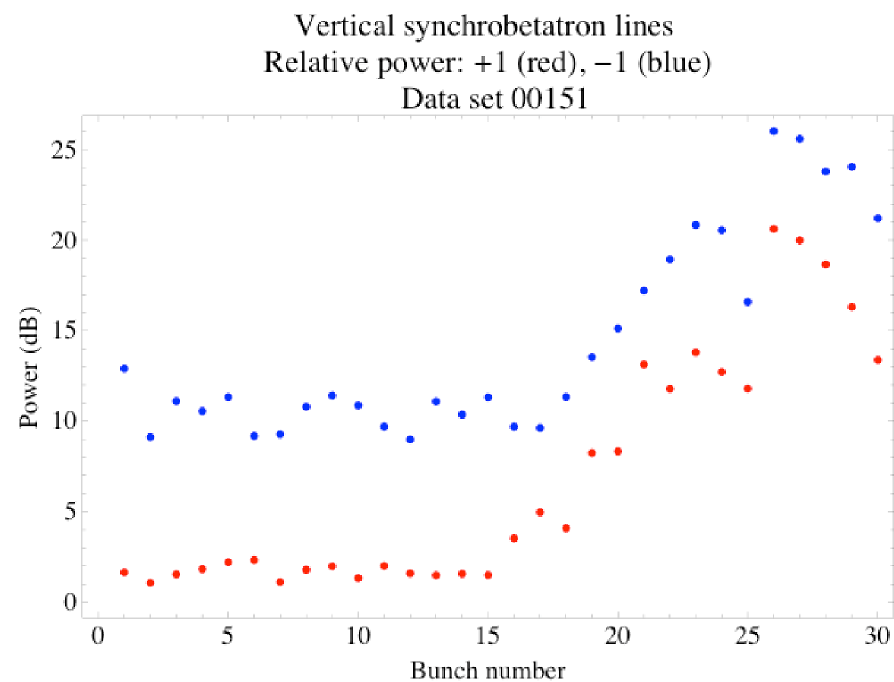
0.75 mA "precursor" bunch:
182 ns before bunch 1
(1960 ns after bunch 30)

Precursor bunch dependence-II

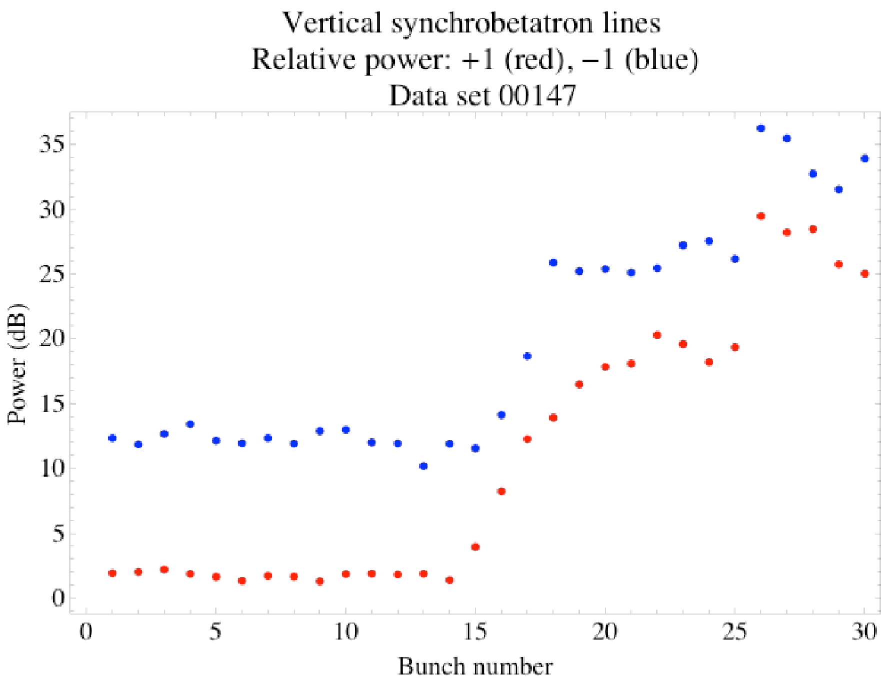


Run 153: precursor bunch 182 ns before bunch 1
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.736
Bunch length = 12.8 mm

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

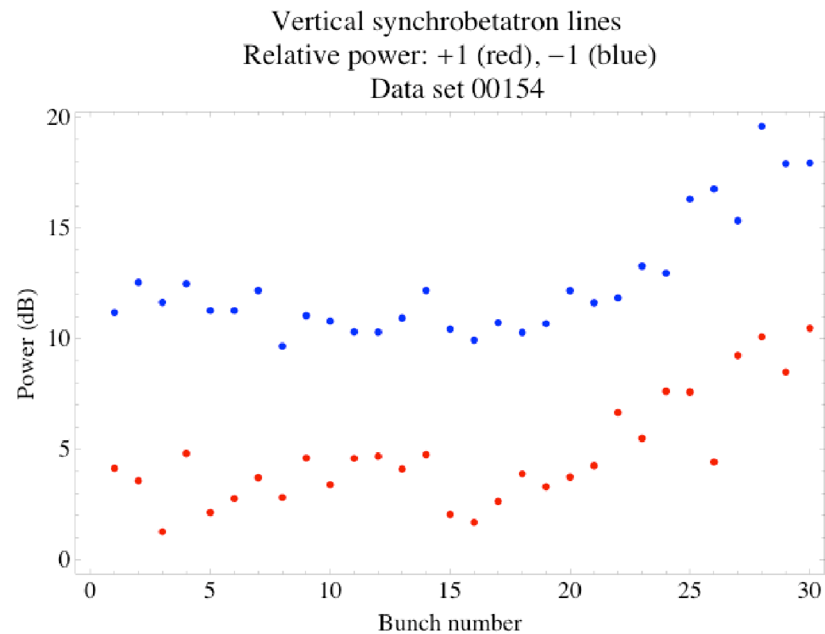


Species dependence

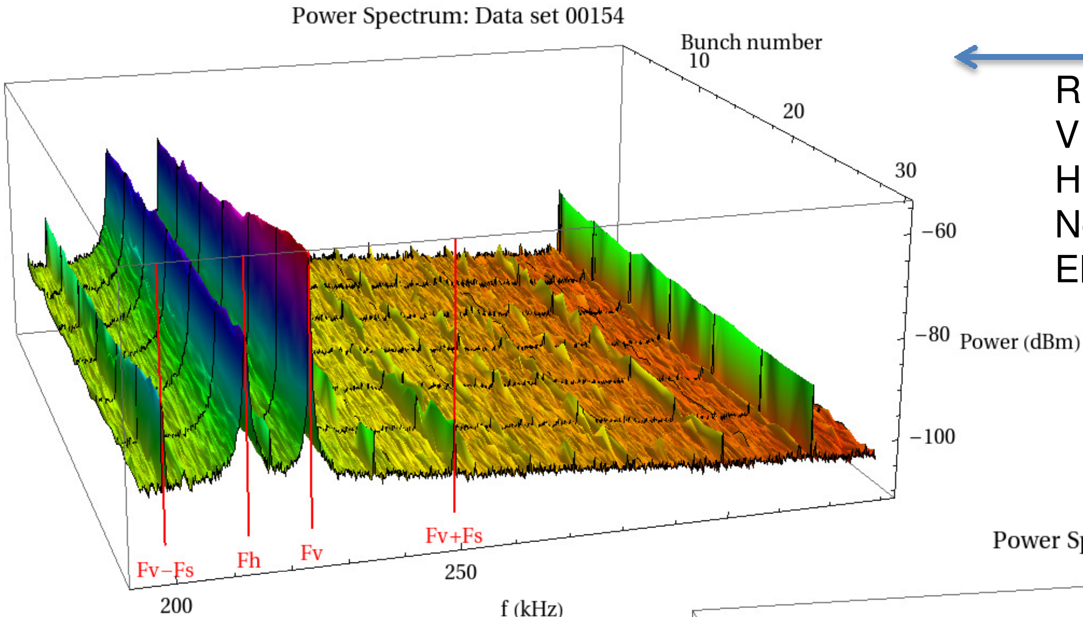


Run 147
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.735
Positrons

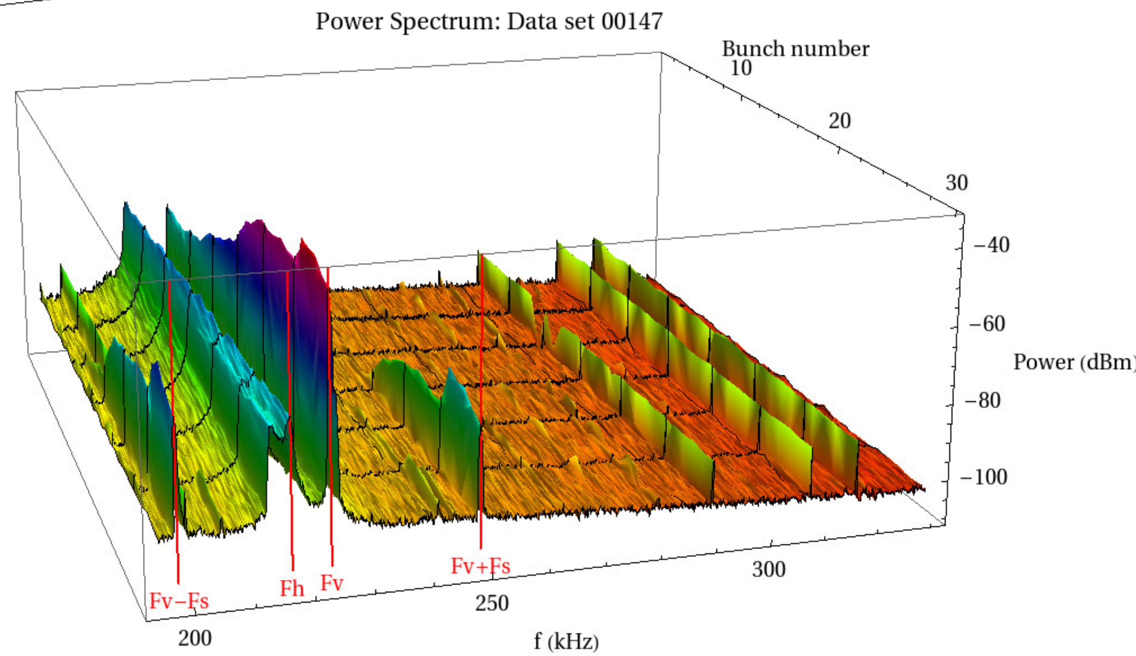
Run 154
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.735
Electrons
Ringwide avg vacuum ~0.6 nTorr



Full spectra, species comparison



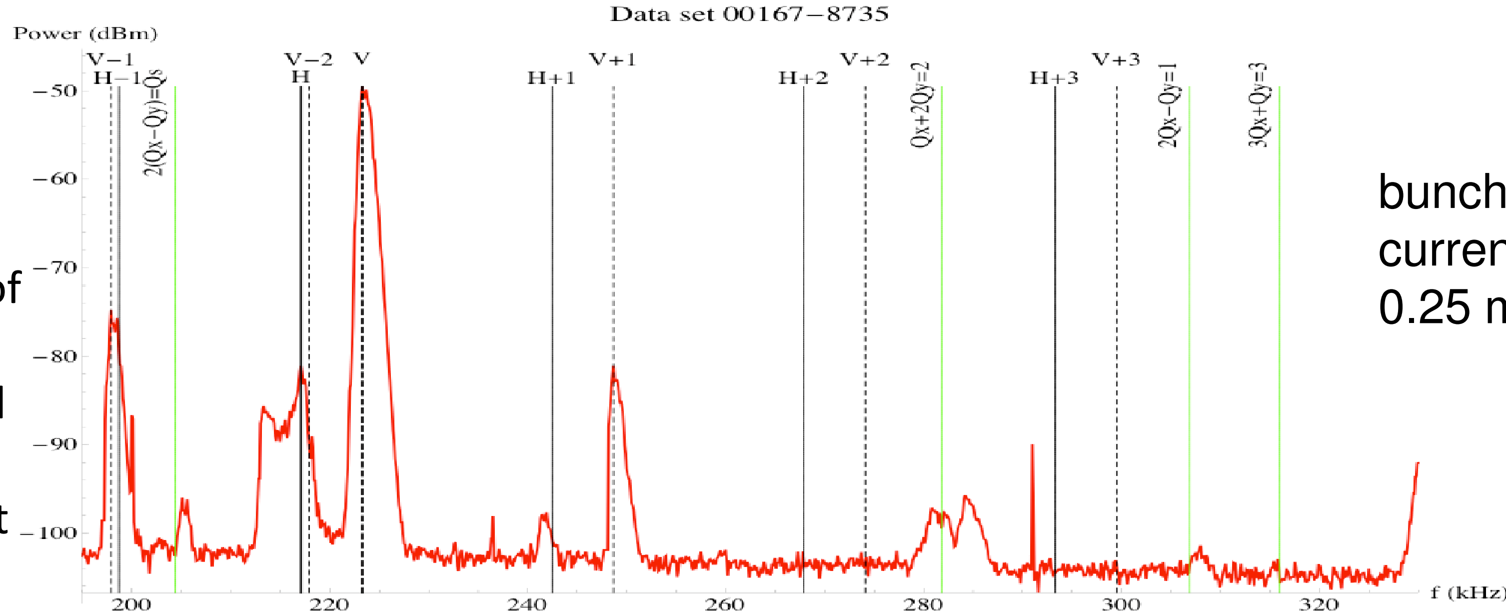
Run 154
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.735
Electrons



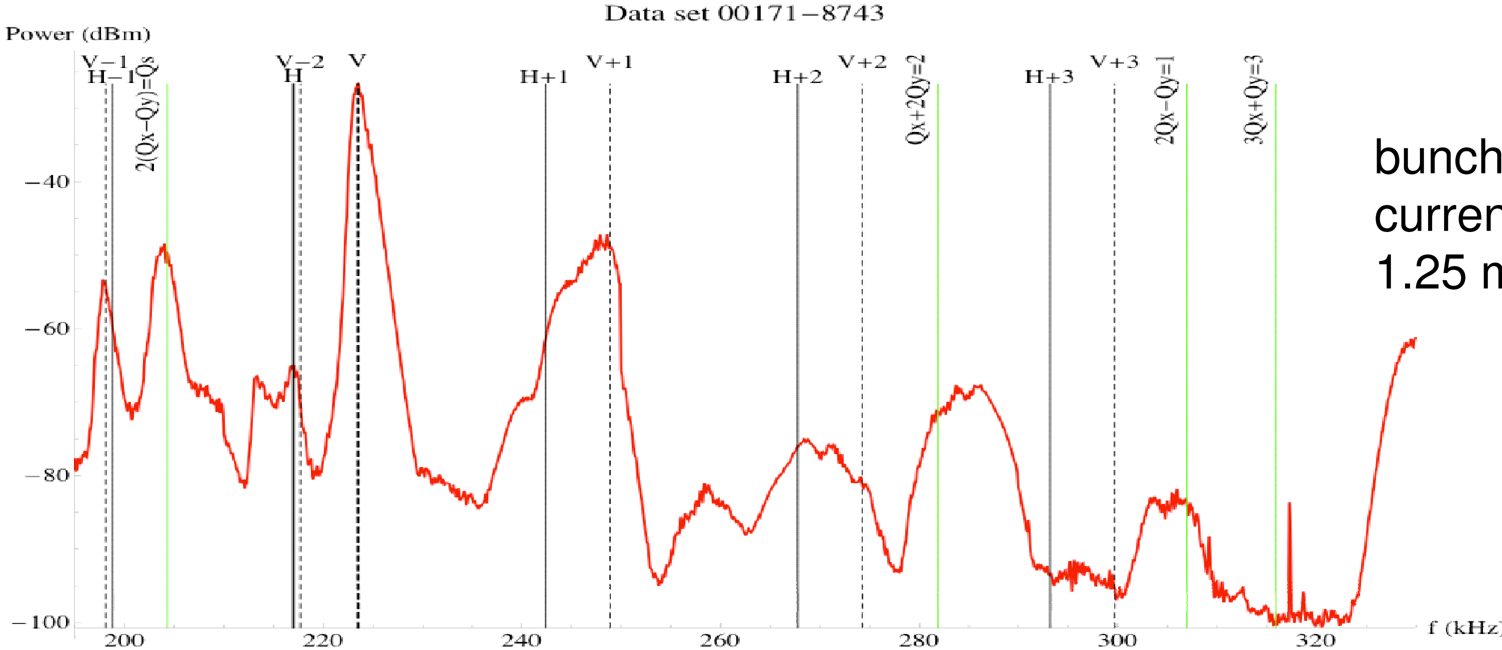
Run 147
V Chromaticity = 1.155
H Chromaticity = 1.33
Nominal current/bunch (mA) = 0.735
Positrons

Single bunch current dependence

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



bunch 30 current = 0.25 mA

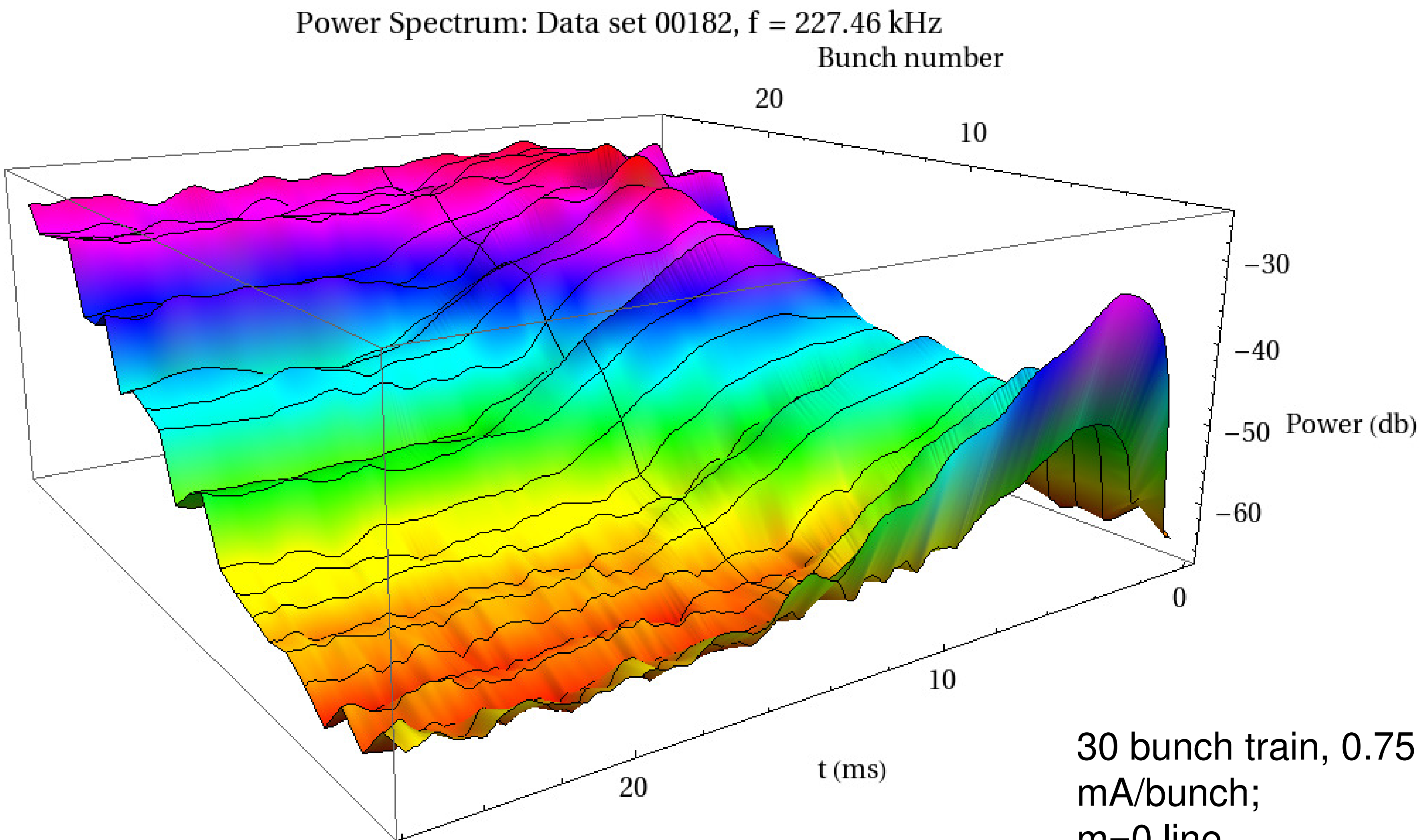


bunch 30 current = 1.25 mA

Measurements of single bunch damping rates

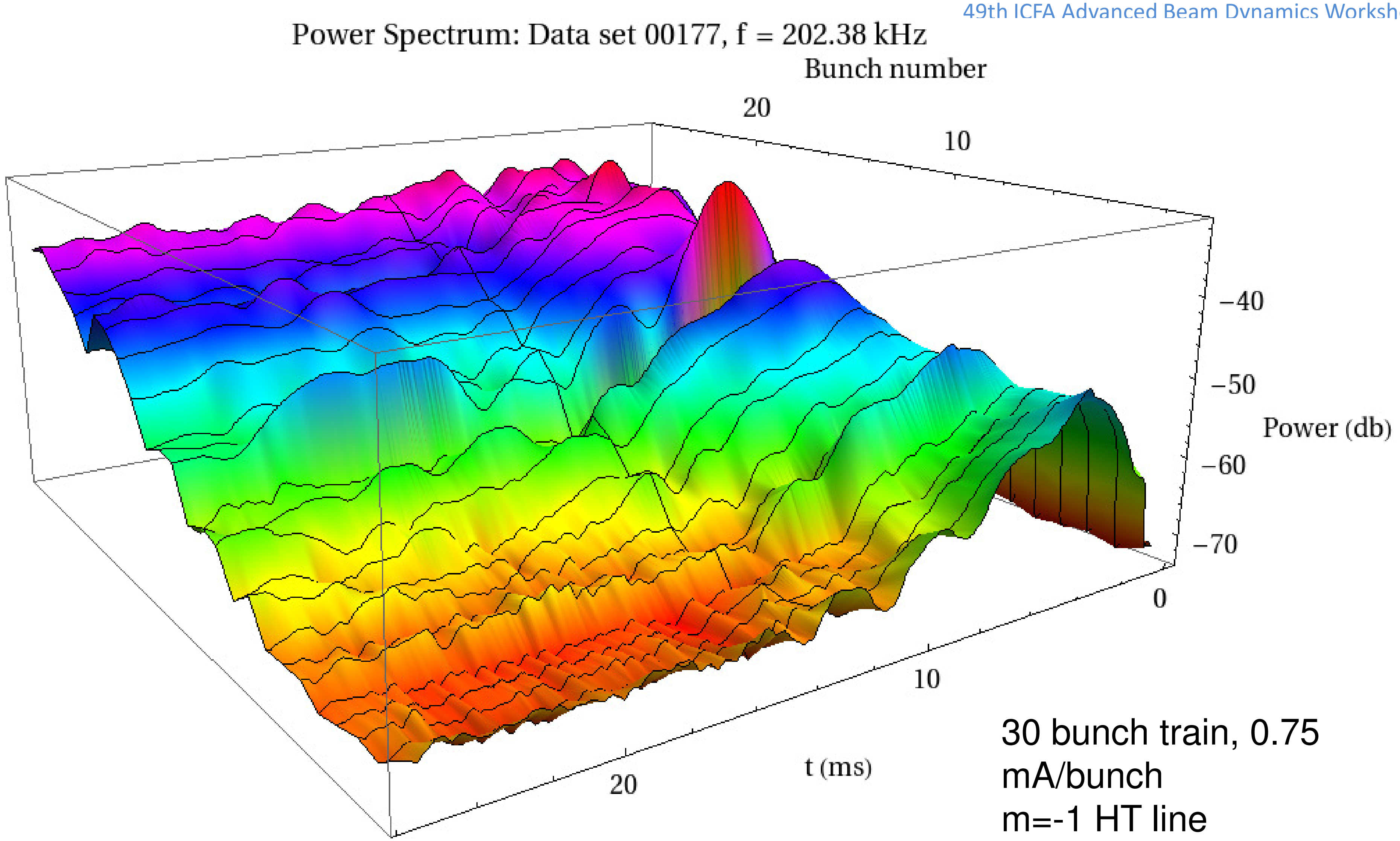
- Bunch-by-bunch damping rate measurements:
  - m = 0 (dipole) mode:
    - drive a single bunch via Transverse Feedback System external modulator with a pulse
    - Observe the m=0 mode from a button BPM, gated on the same bunch
    - Measure the damping rate of the m=0 line's power after the drive is 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).

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

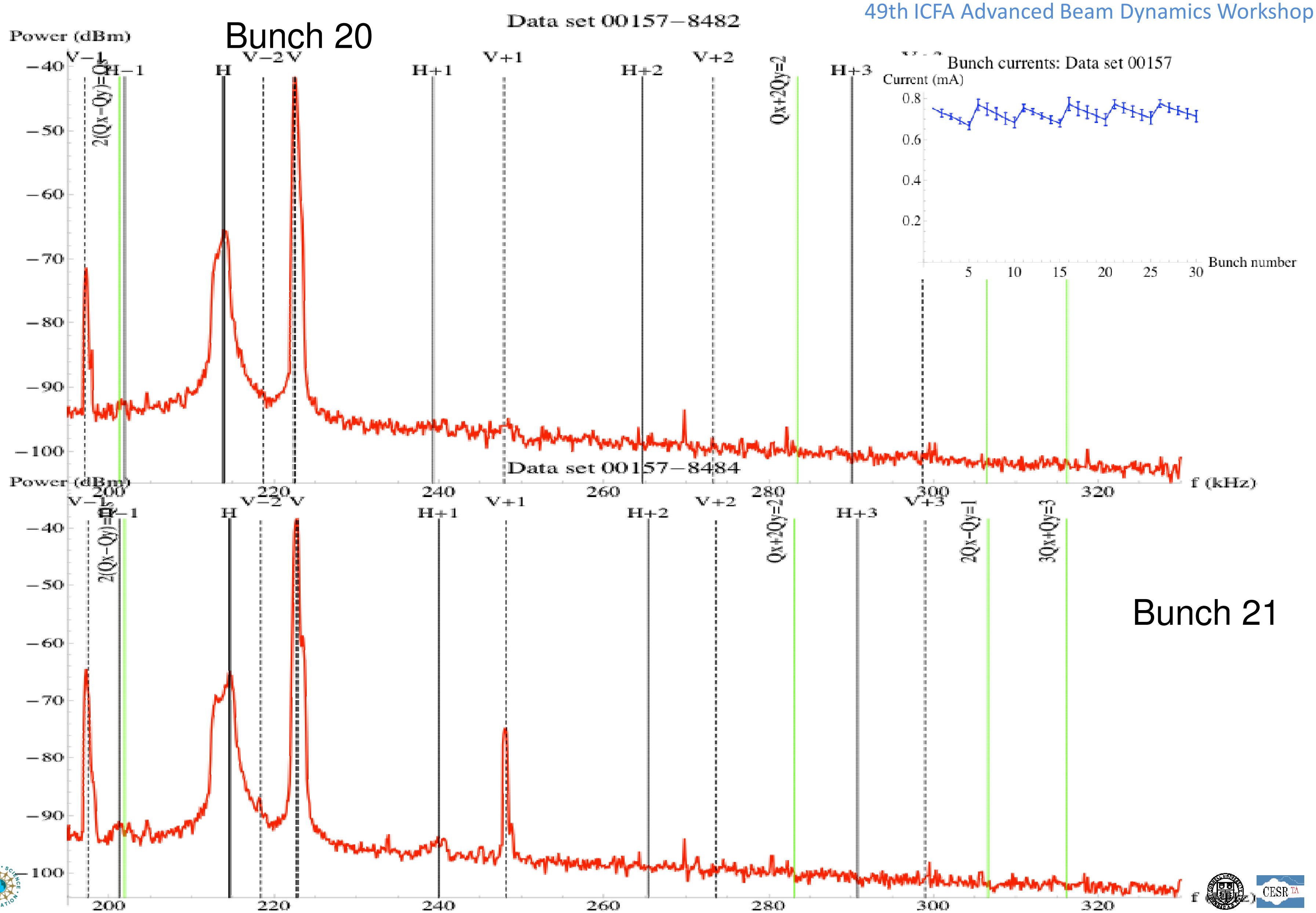
- The basic observation is that, under a variety of conditions, single-bunch frequency spectra in multi-bunch positron trains exhibit the m=+/- 1 head-tail (HT) lines, separated from the vertical line by the synchrotron frequency, for some of the bunches during the train.
- For a 30 bunch train with 0.75 mA/bunch, the onset of these lines occurs at a cloud density (near the beam) of around $9x10^{11}/m^{-3}$.
- The betatron lines exhibit structure which varies along the train. The vertical line power grows along the train and has a structure that is not understood.
- The onset of the HT lines depends strongly on the vertical chromaticity, the beam current and the number of bunches.
- For a 45 bunch train, the HT lines have an onset around $11\text{-}12x10^{11}/m^{-3}$, and a maximum amplitude around bunch 30-35; the line amplitude is reduced for later bunches.
- There is a weak dependence on the synchrotron tune, the vertical beam size, the vertical feedback.

Conclusions

- Under some conditions, the first bunch in the train also exhibits a head-tail line (m=-1 only). The presence of a "precursor" bunch eliminates the m=-1 signal in the first bunch, and also leads to the onset of the HT lines at a later bunch in the train. The implication is that there is a significant cloud density near the beam which lasts at least a few microseconds. Indications from RFA measurements and simulations indicate this "trapped" cloud may be in the quadrupoles and wigglers
- Under identical conditions, HT lines also appear in electron trains, but the onset is later in the train, and develops more slowly, than for positrons.
- There is a strong dependence of the HT line structure observed on last bunch in a 30 bunch train, as a function of the current in that bunch.
- We have made preliminary measurements of damping rates of single bunches in 30 bunch trains. A more comprehensive set of measurements in the future will shed more light on the effective electron cloud impedance.
- For both sets of measurements, we need to make more checks for systematics: looking at different BPM's, for example.

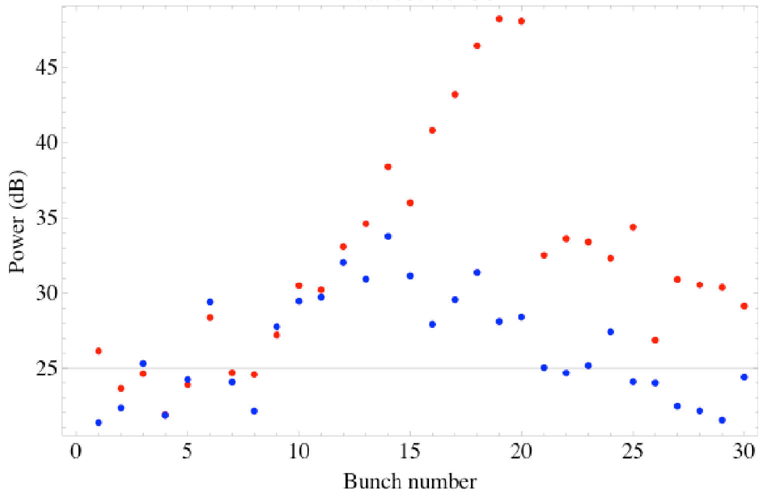
- Backup slides

HT m=+1 line appearance at bunch 21

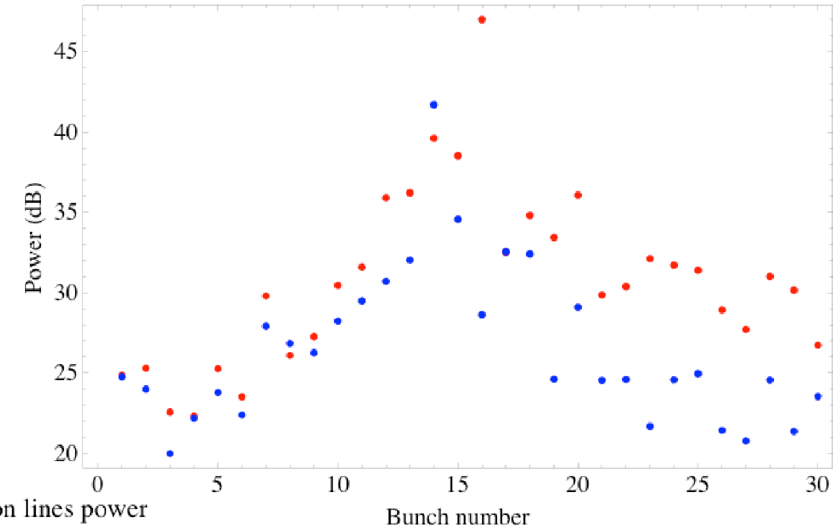


Ratio of betatron power to HT-line power (vertical)

Vertical betatron lines power
relative to vertical m=+/−1 line power
(m=+1)(red) (m=−1)(blue)
Data set 00157

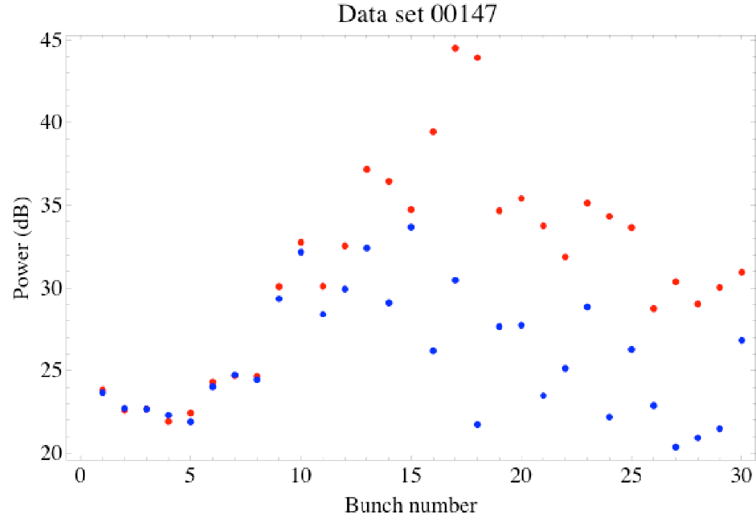


Vertical betatron lines power
relative to vertical m=+/−1 line power
(m=+1)(red) (m=−1)(blue)
Data set 00166

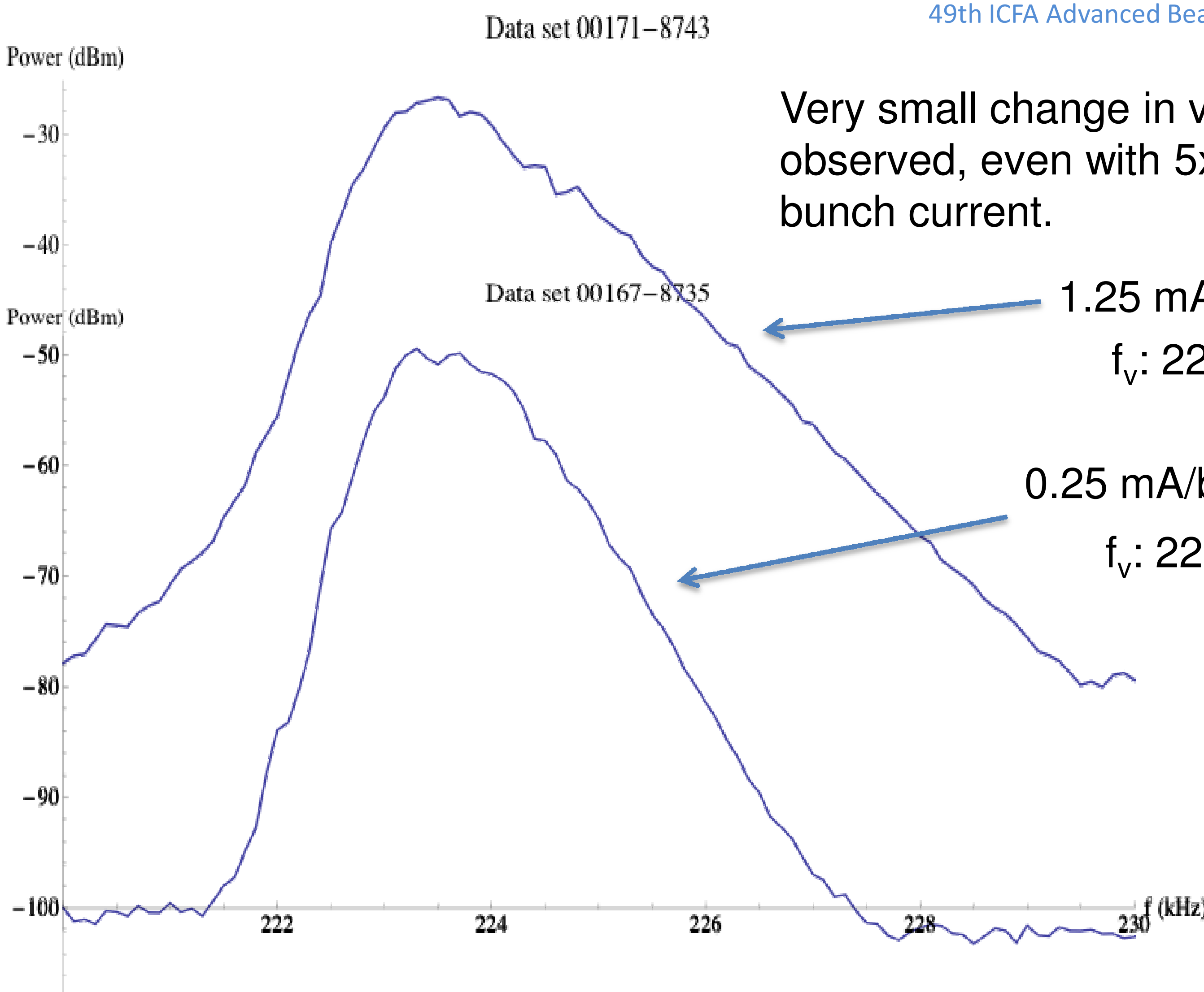


Runs 147, 157, 166 are shown. These were performed at different times under nominally the same conditions.

Vertical betatron lines power
relative to vertical m=+/−1 line power
(m=+1)(red) (m=−1)(blue)
Data set 00147



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