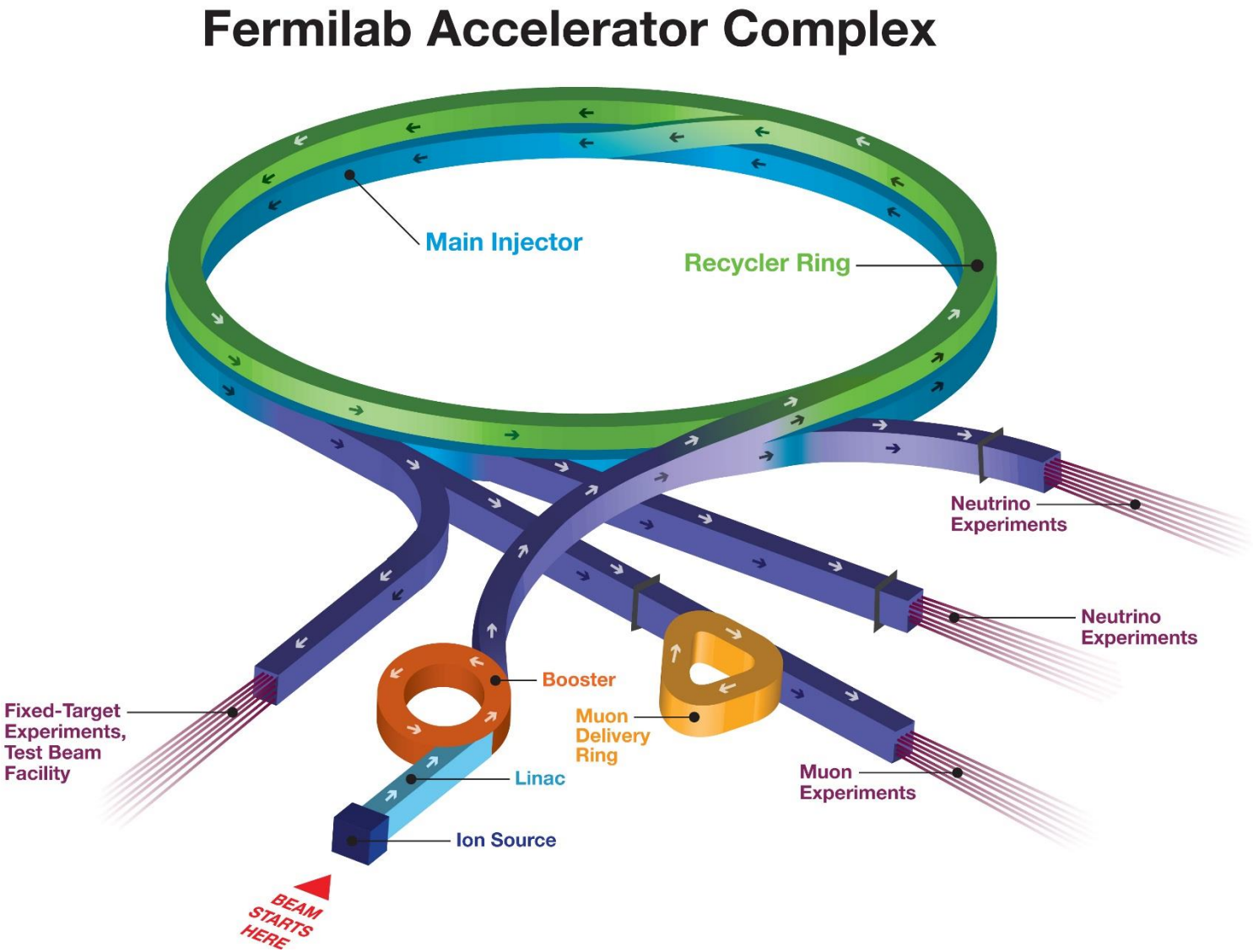
Fast Transverse Instability and Electron Cloud Measurements in the Fermilab Recycler

11/13/14 Contributed Talk

Jeffrey Eldred (IU & Fermilab)

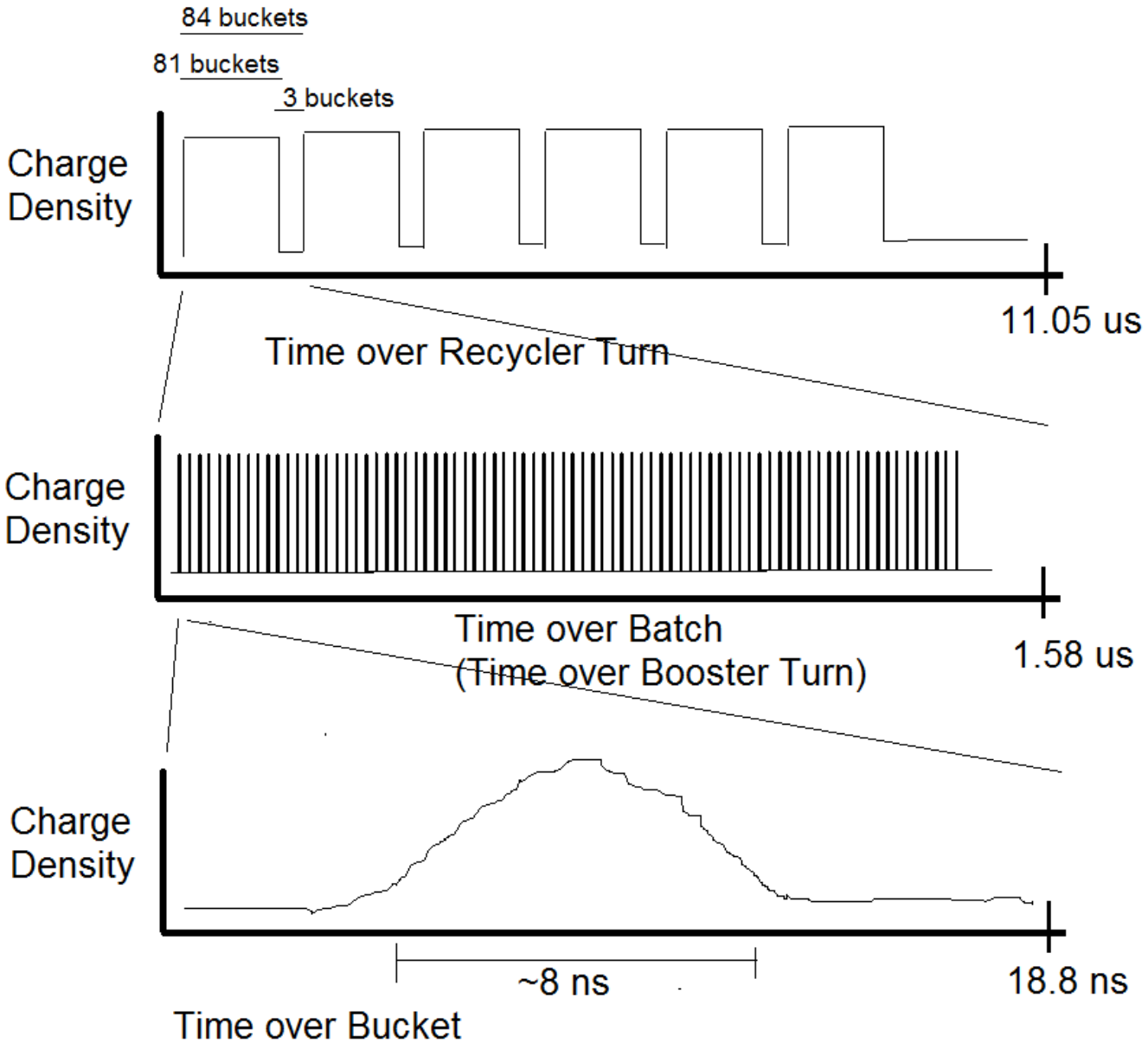
Phil Adamson, David Capista, Nathan Eddy, Yichen Ji (IIT), Ioanis Kourbanis, Denton Morris, Jayakar Thangaraj, Ming-Jen Yang, Robert Zwaska

The Recycler



Recycler Instability

- **Brand new**
  - First seen this past July
- **Transverse Instability**
  - Horizontal betatron oscillation and emittance growth.
- **Very Fast**
  - 25% loss in 150 revolutions.
- **Electron Cloud**
  - Exploring this explanation as a candidate.
- **First High-Intensity Batch**
  - Preferentially impacts first high-intensity batch.



588 buckets in Recycler
84 buckets in Booster

588 = 7x84 buckets

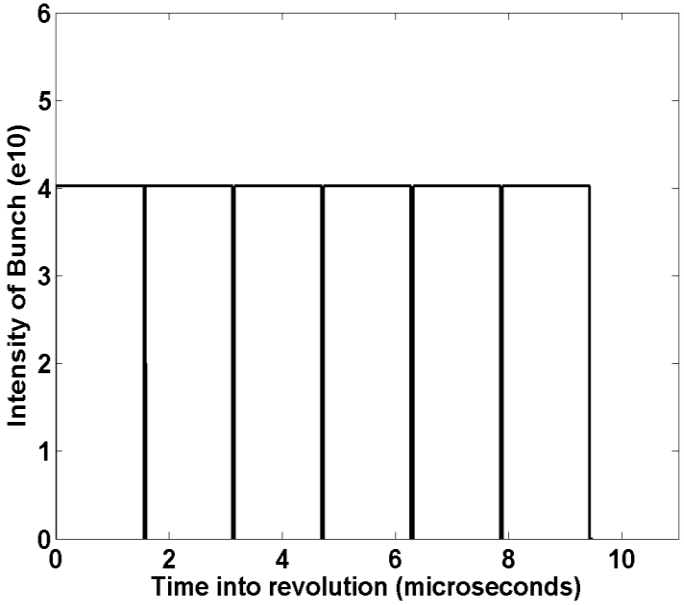
Recycler stores 6 batches + a kicker gap

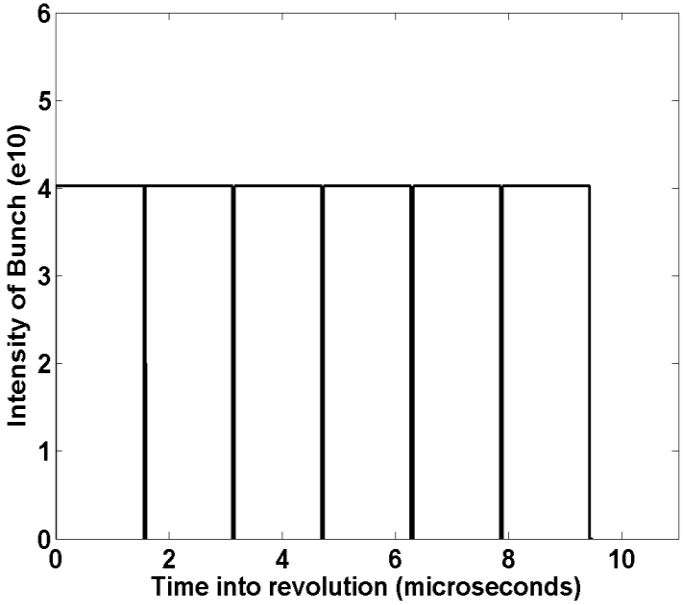
81 out of 84 buckets filled in a batch

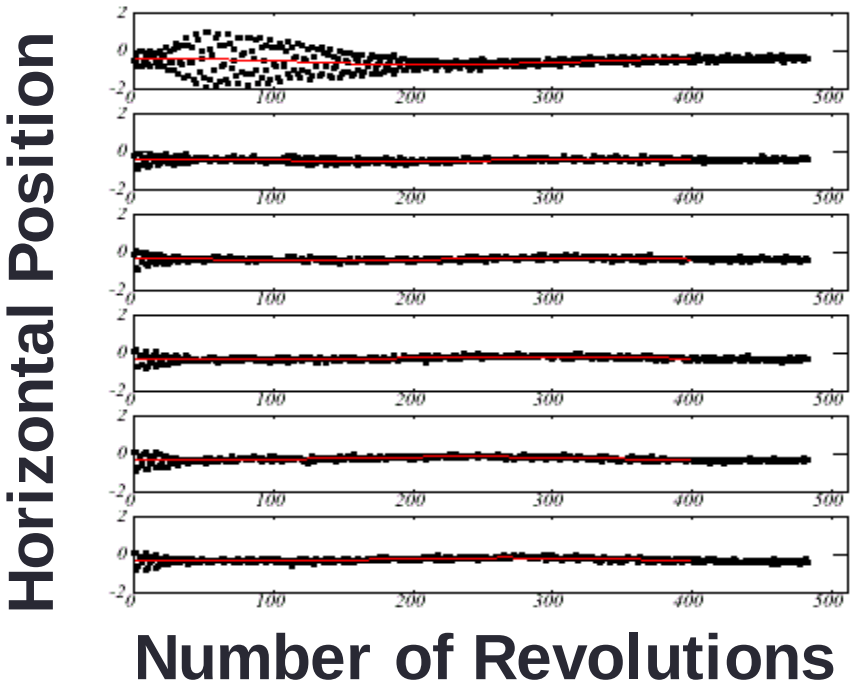
Five 3-bucket gaps
One 87-bucket gap

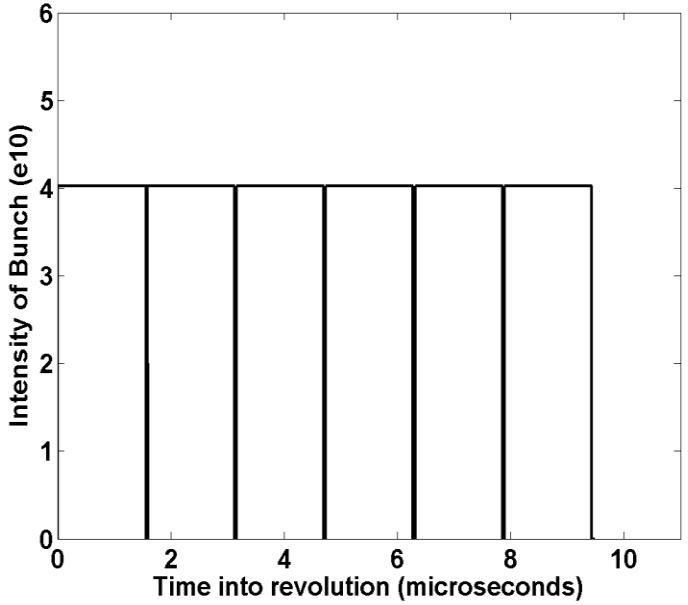
1 bucket <-> 18.8 ns
1 batch <-> 1.58 us
1 turn <-> 11.05 us

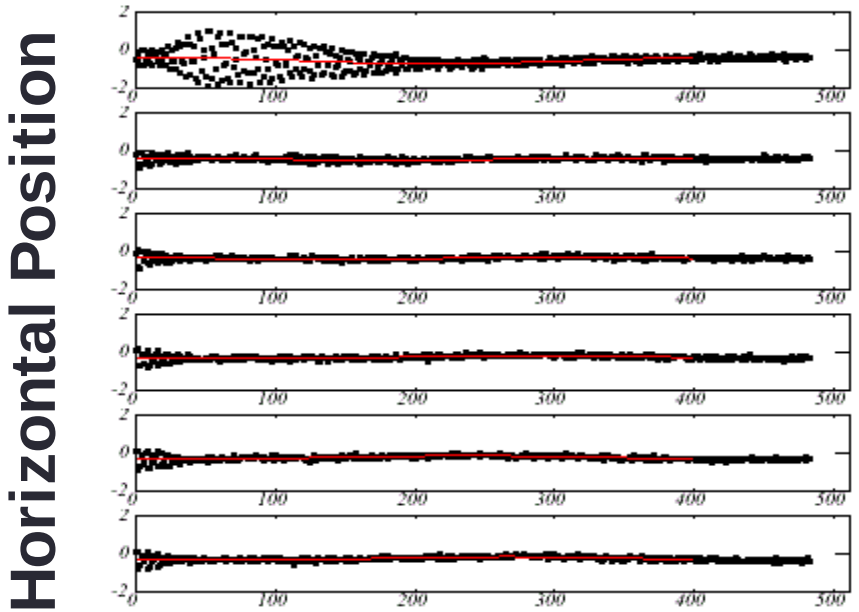
1 sig bunch length ~ 2ns
4 sig bunc length ~ 8ns

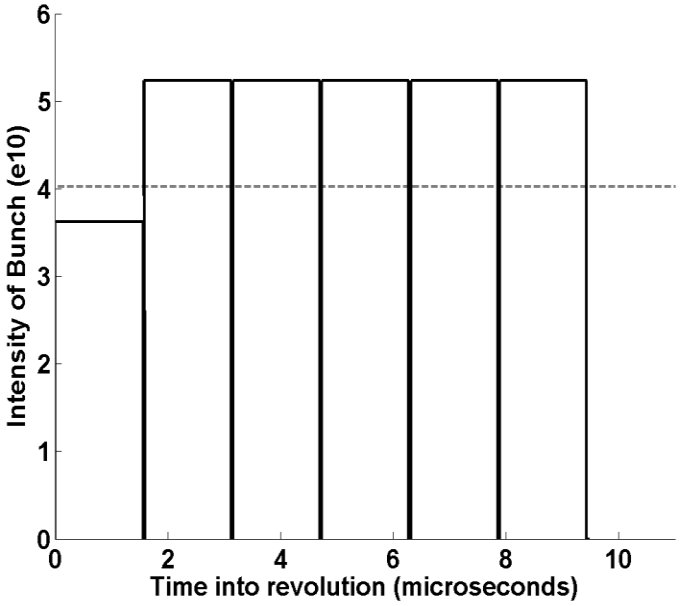

Intensity of Bunch (e10)
Time into revolution (microseconds)
0
1
2
3
4
5
6
0
2
4
6
8
10

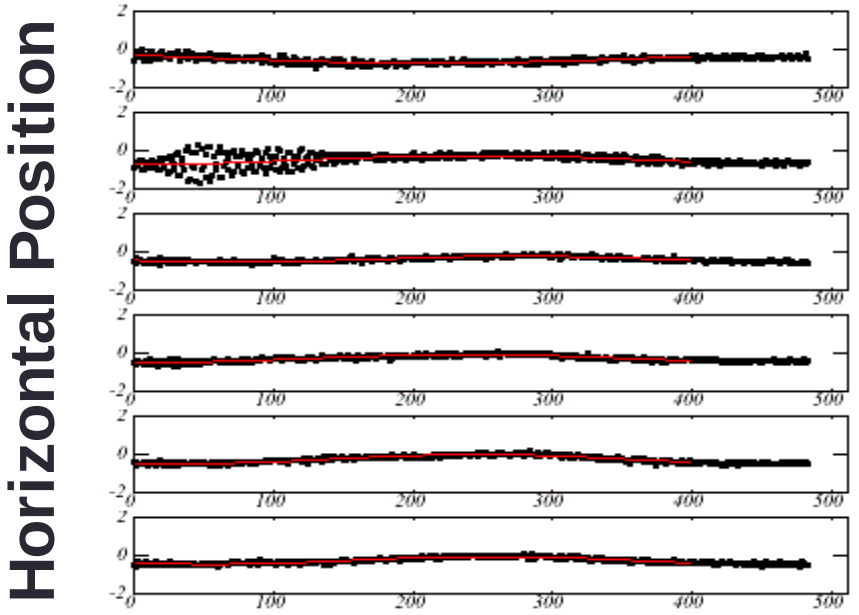

Intensity of Bunch (e10)
Time into revolution (microseconds)
0
1
2
3
4
5
6
0
2
4
6
8
10


Horizontal Position
Number of Revolutions


Intensity of Bunch (e10)
Time into revolution (microseconds)

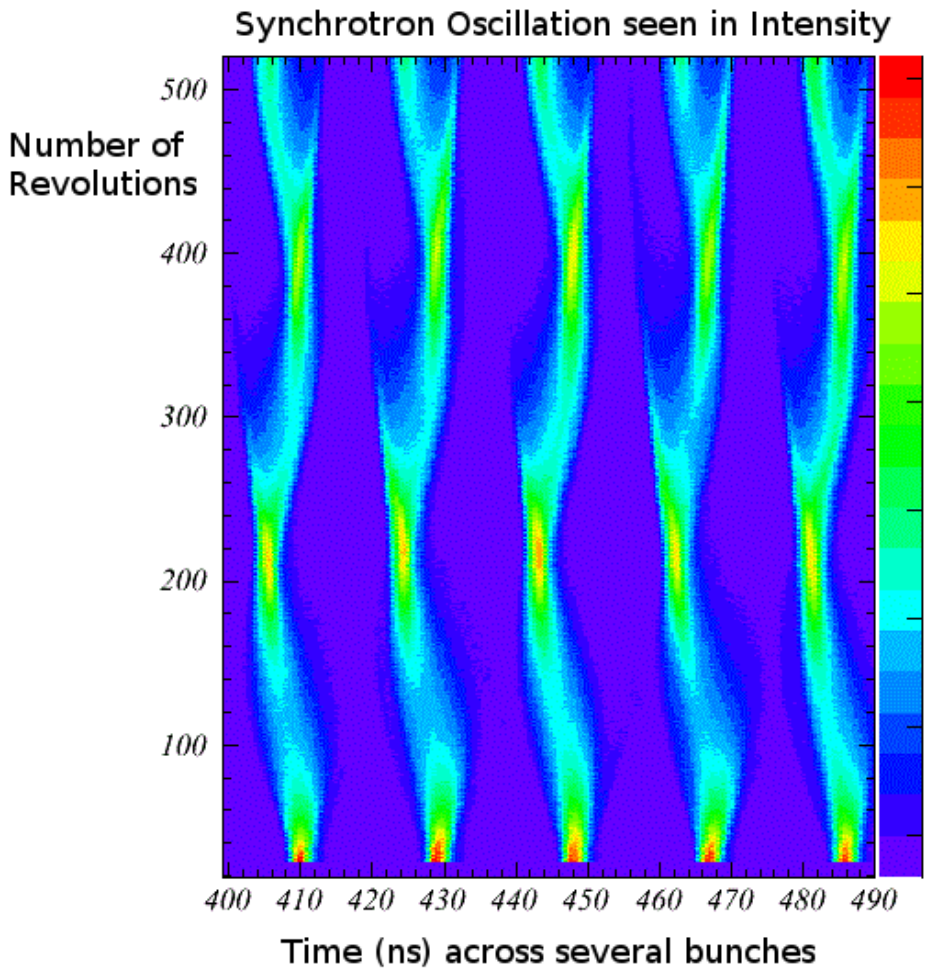

Horizontal Position
Number of Revolutions

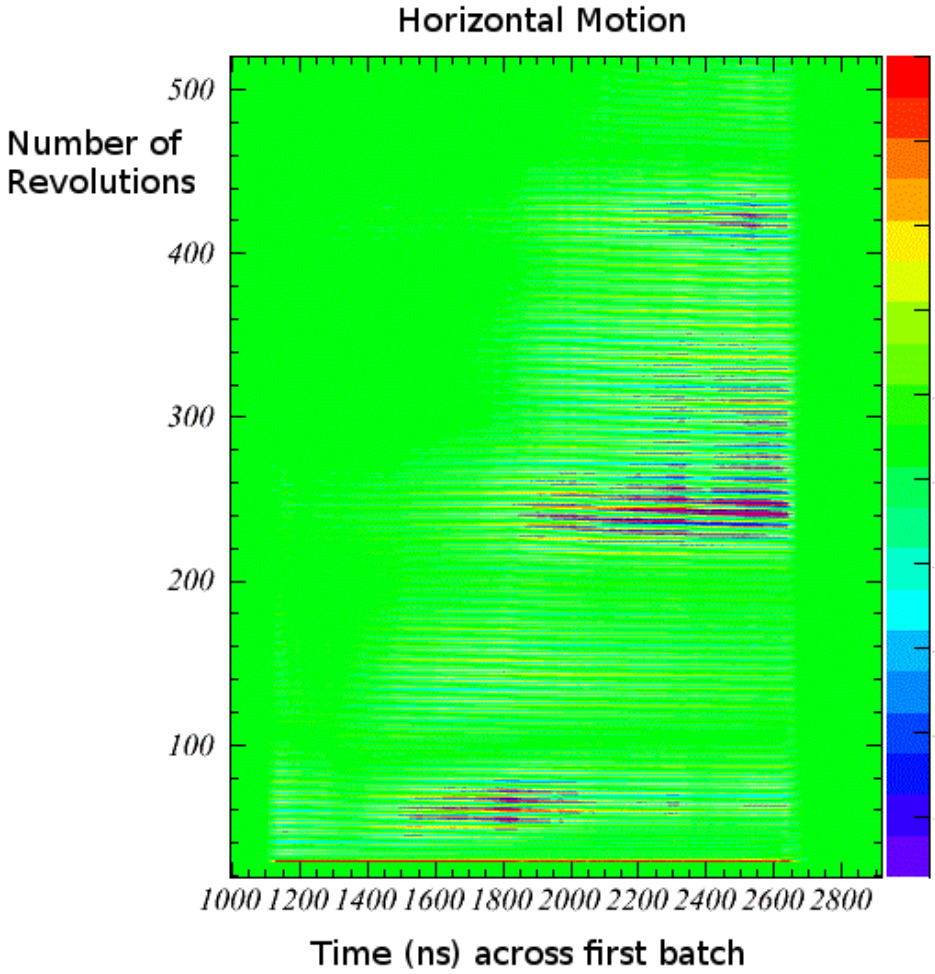

Intensity of Bunch (e10)
Time into revolution (microseconds)


Horizontal Position

Beam Position Measurements

Wall Current Monitor & Stripline BPM



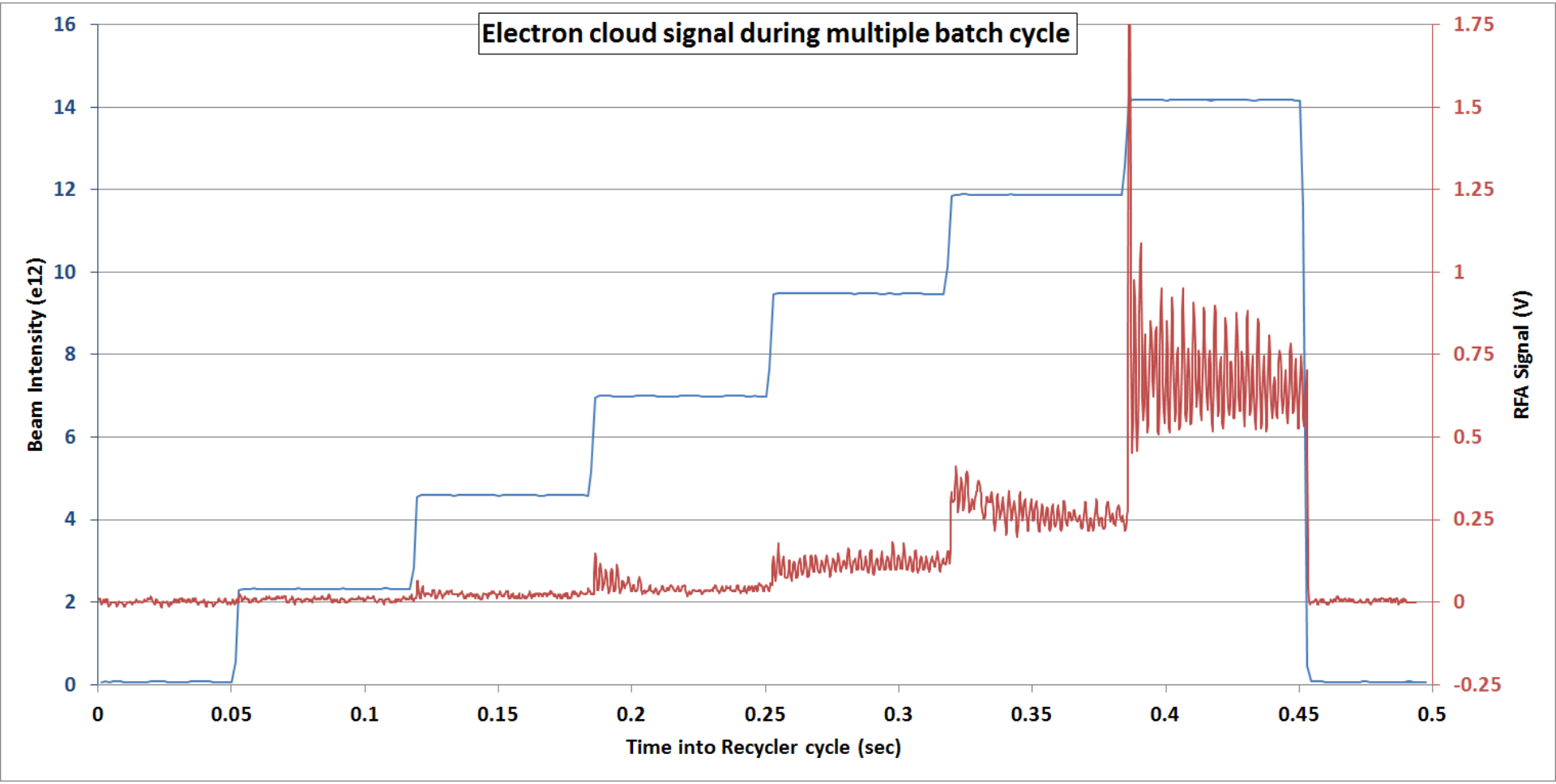


Electron Cloud Measurements

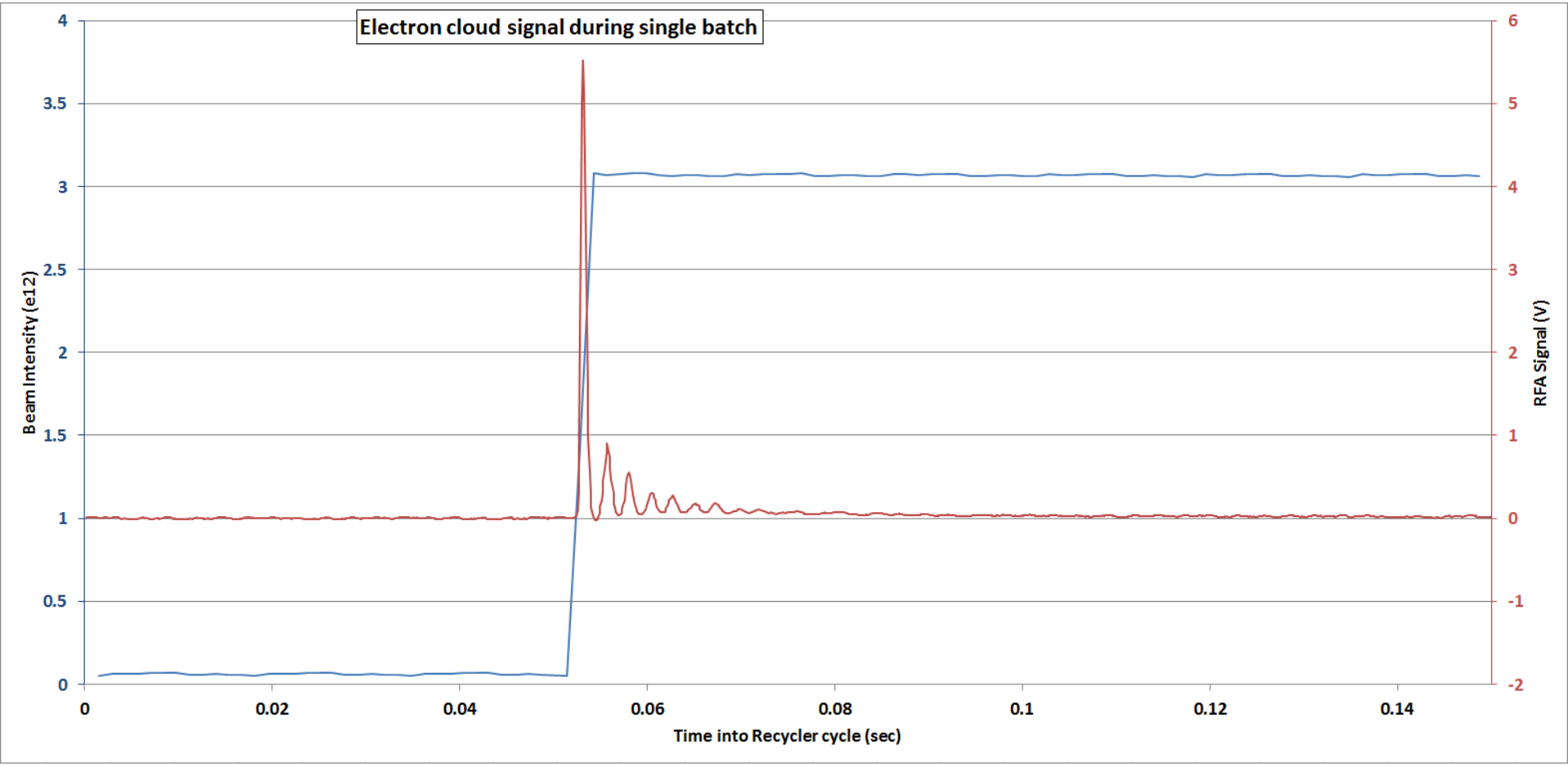
Retarding Field Analyzer (RFA)

- Installed in the Recycler.
- Established ecloud detector.
- Collector cup directly measures ecloud flux.
- Grid contains secondary electrons.

RFA Measurements - Low Int Multiple Batch

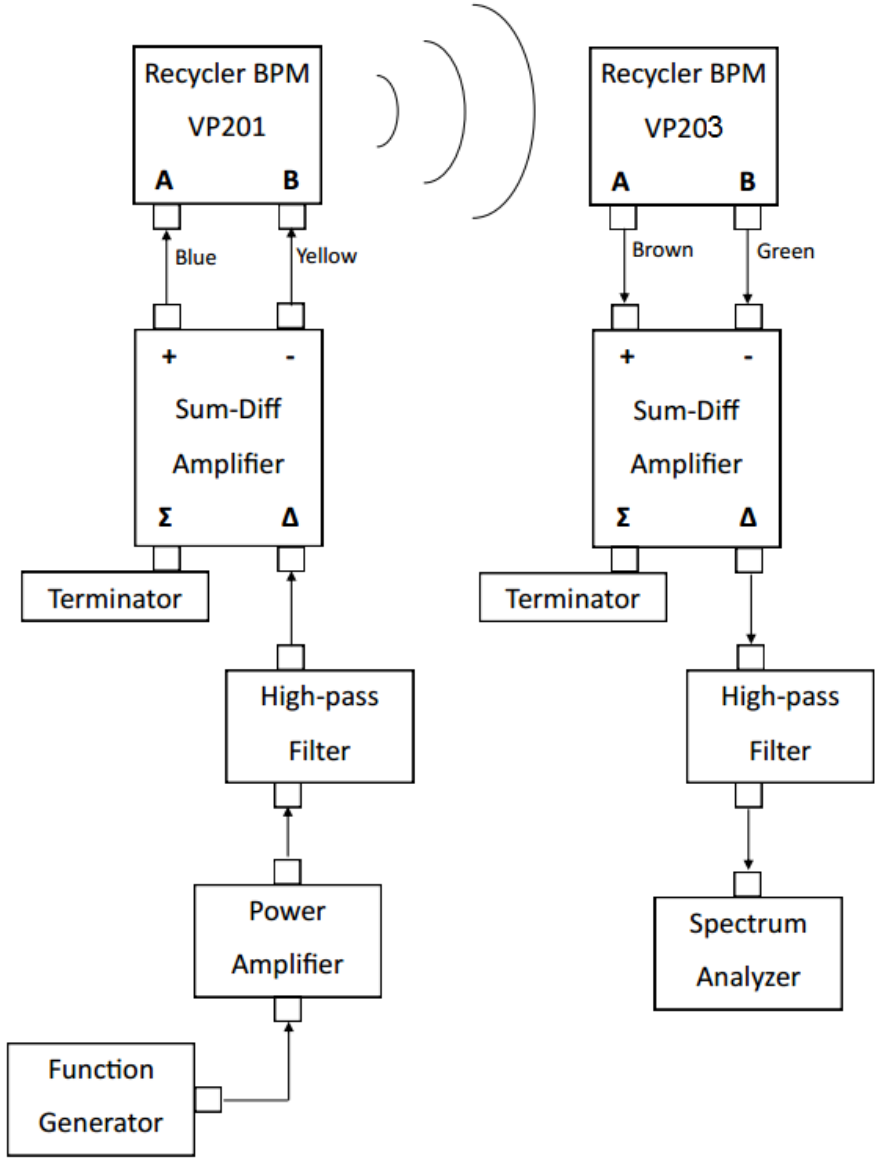


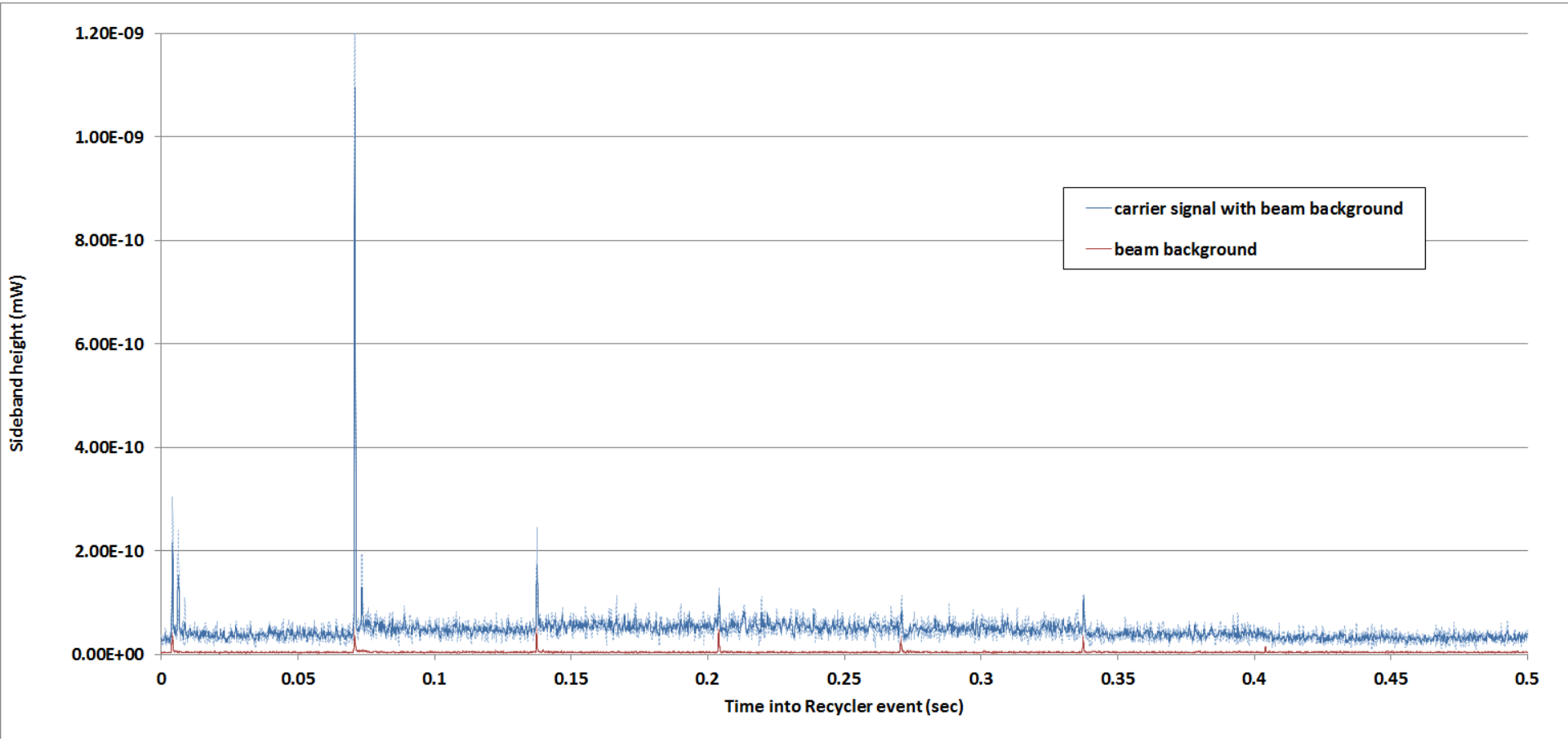
RFA Measurements - High Int Single Batch

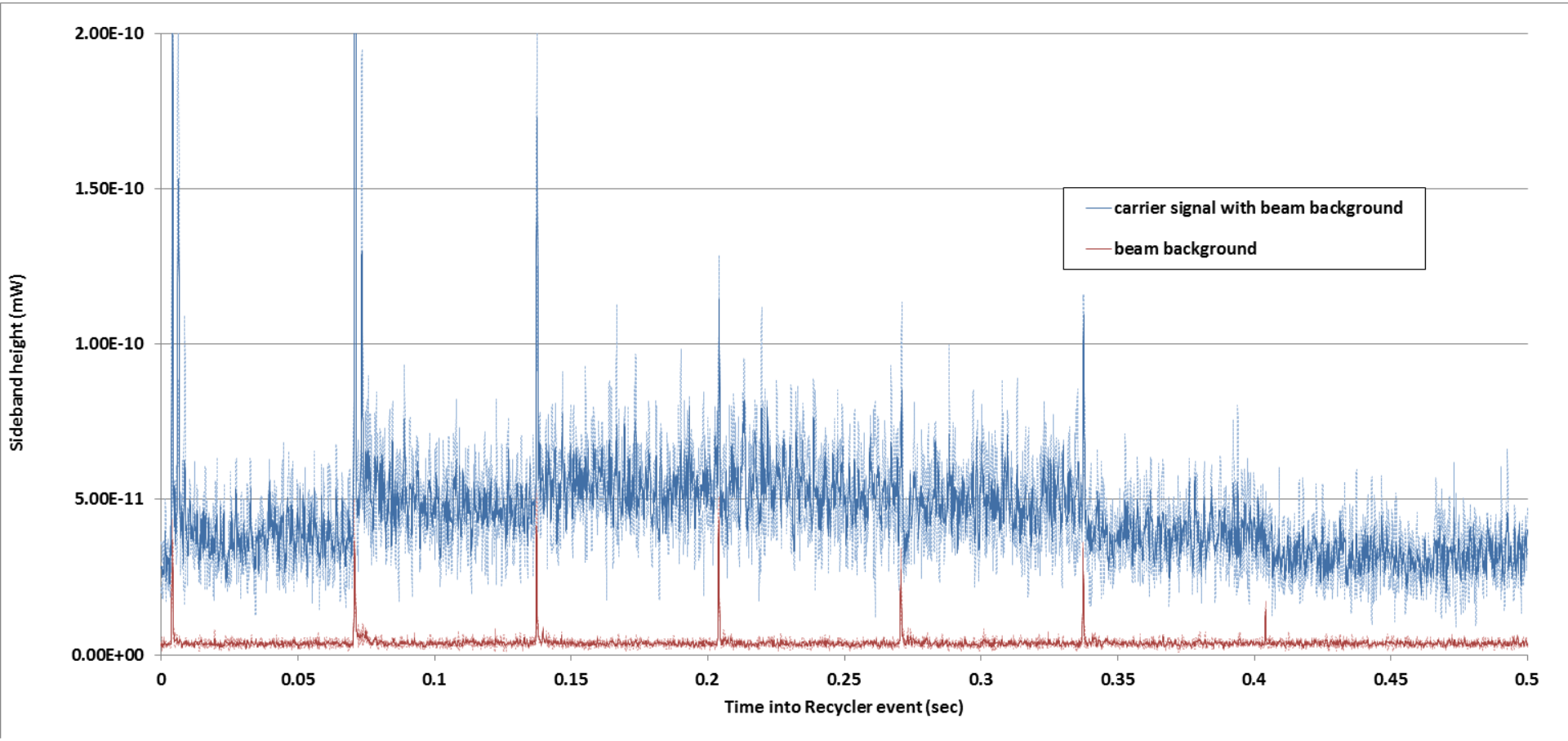


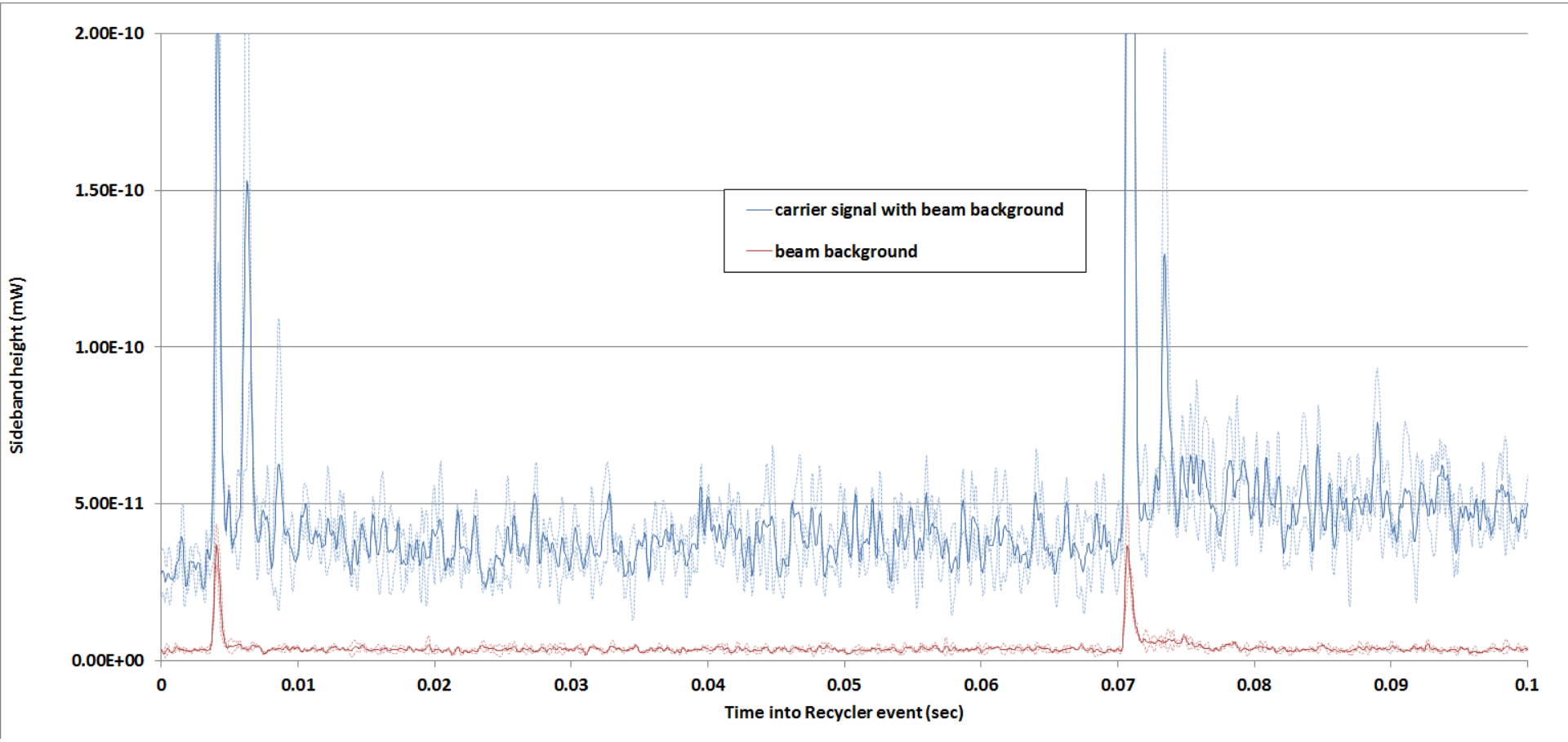
Microwave Measurement Schematic

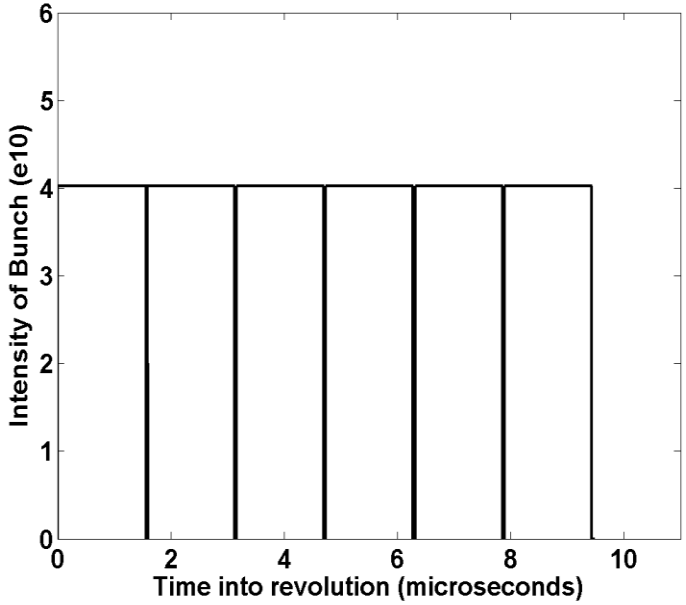
- ~ 1.9 GHz carrier frequency is propagated through beampipe.
- The presence of ecloud causes a phase-delay
- The phase modulation occurs at the beam harmonics ~90 kHz.
- The spectrum analyzer should see 90 kHz sidebands on either side of the carrier frequency.

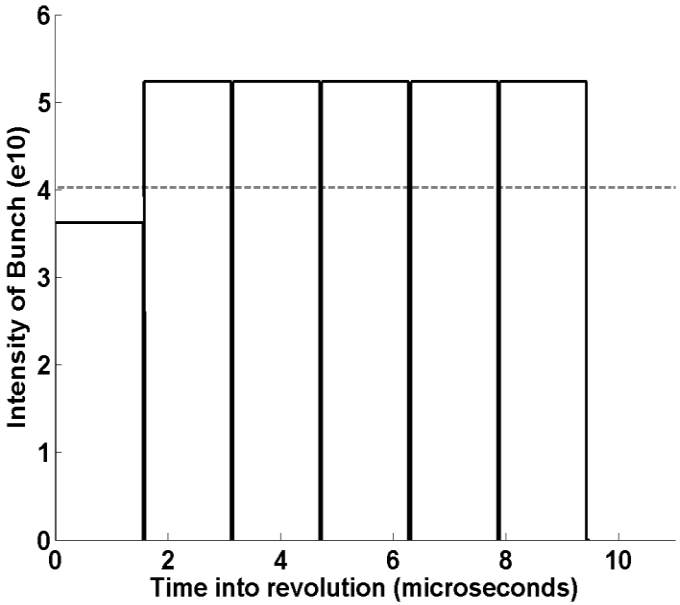



1.20E-09
1.00E-09
8.00E-10
6.00E-10
4.00E-10
2.00E-10
0.00E+00
Sideband height (mW)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Time into Recycler event (sec)
carrier signal with beam background
beam background

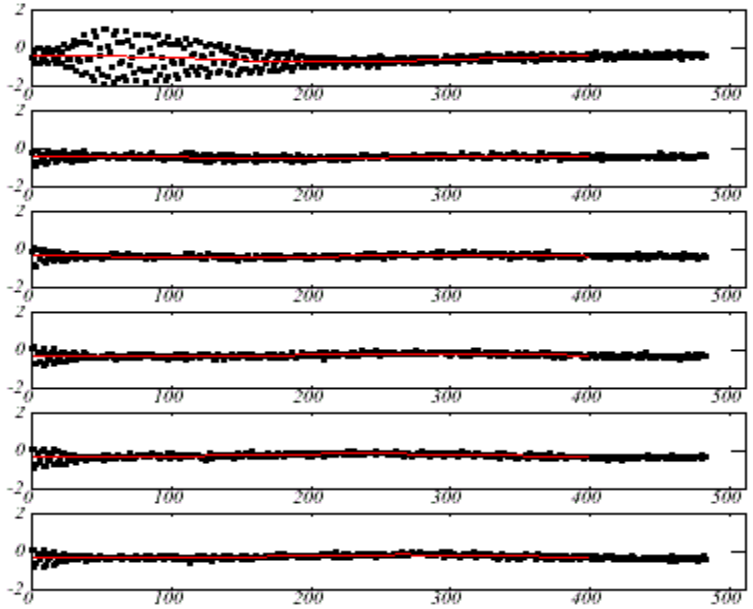

2.00E-10
1.50E-10
1.00E-10
5.00E-11
0.00E+00
Sideband height (mW)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
Time into Recycler event (sec)
carrier signal with beam background
beam background


2.00E-10
1.50E-10
1.00E-10
5.00E-11
0.00E+00
Sideband height (mW)
carrier signal with beam background
beam background
0
0.01
0.02
0.03
0.04
0.05
0.06
0.07
0.08
0.09
0.1
Time into Recycler event (sec)



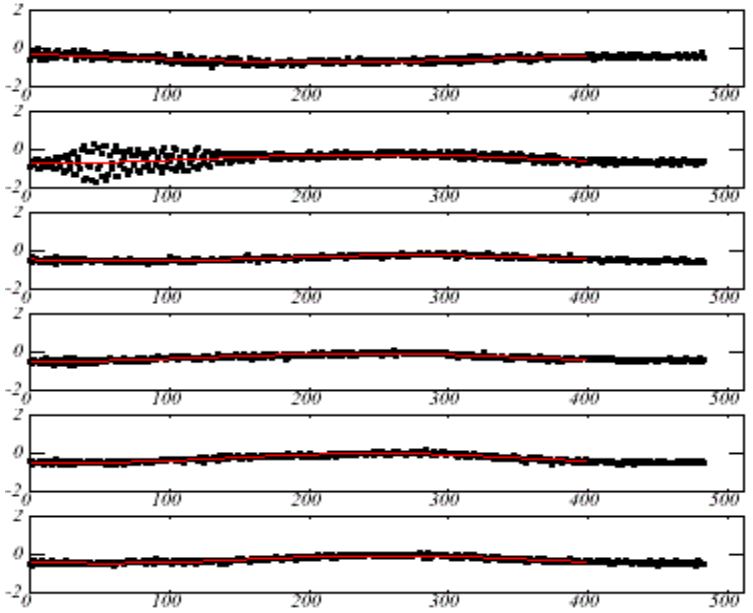


Horizontal Position



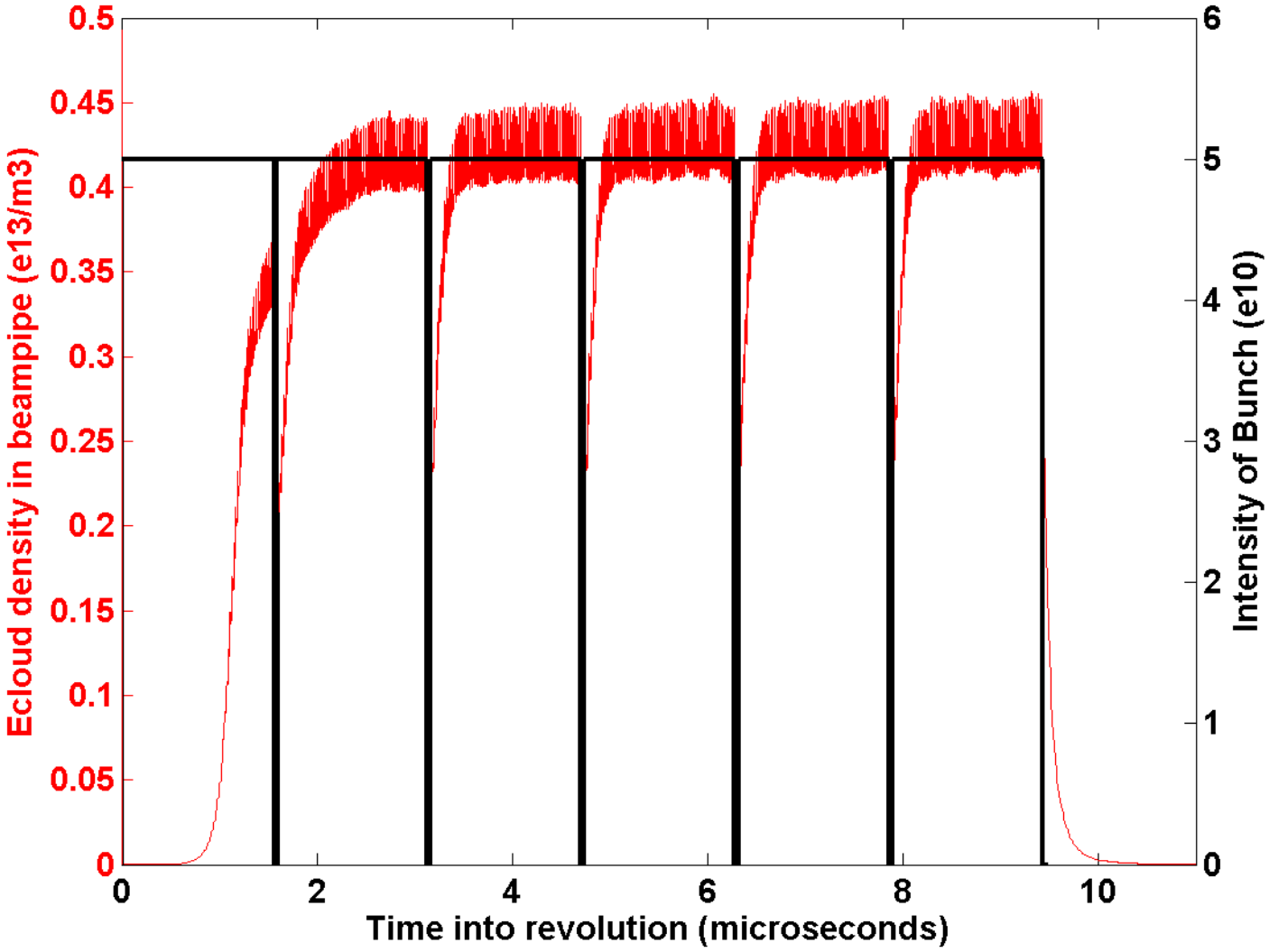
Number of Revolutions

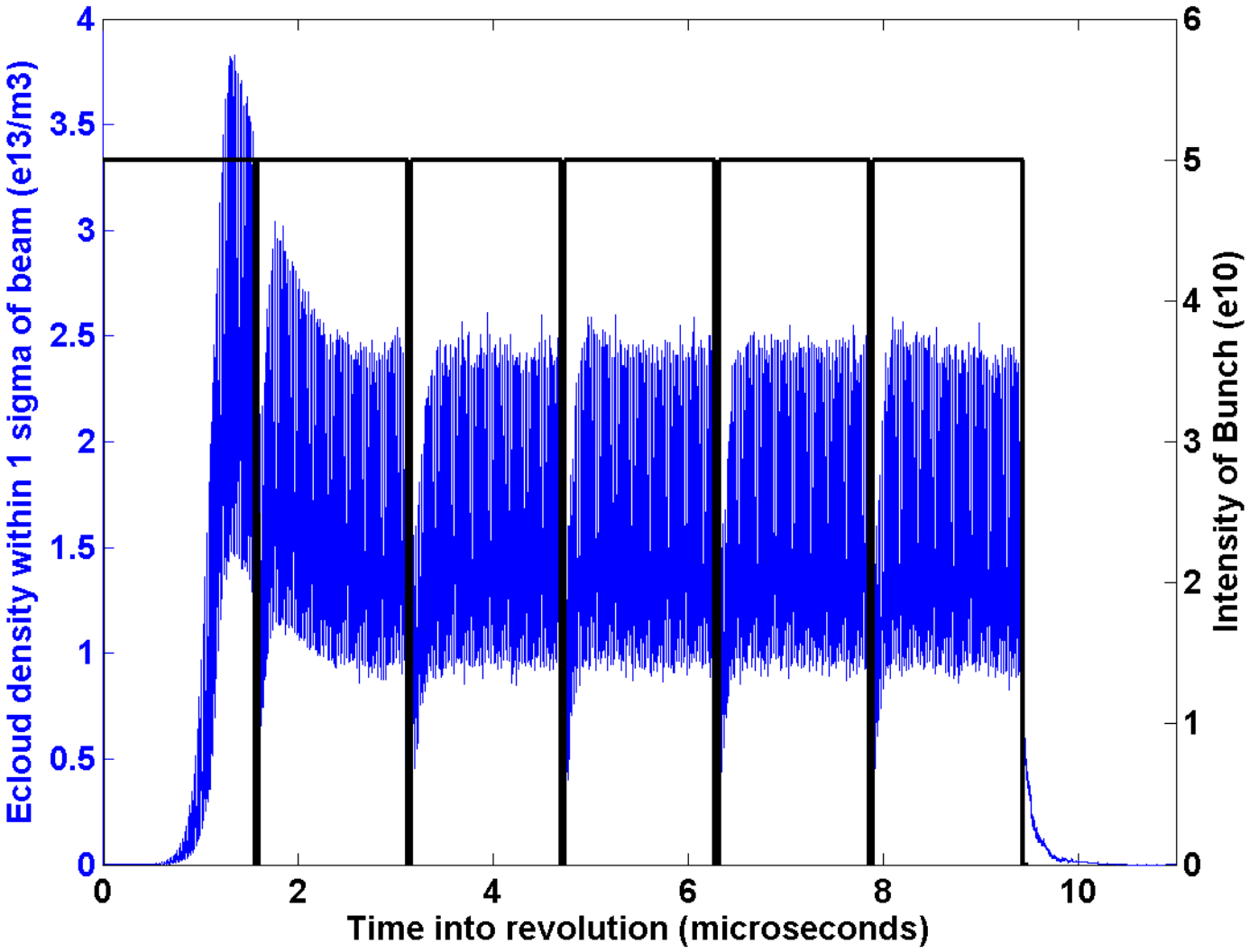
Horizontal Position

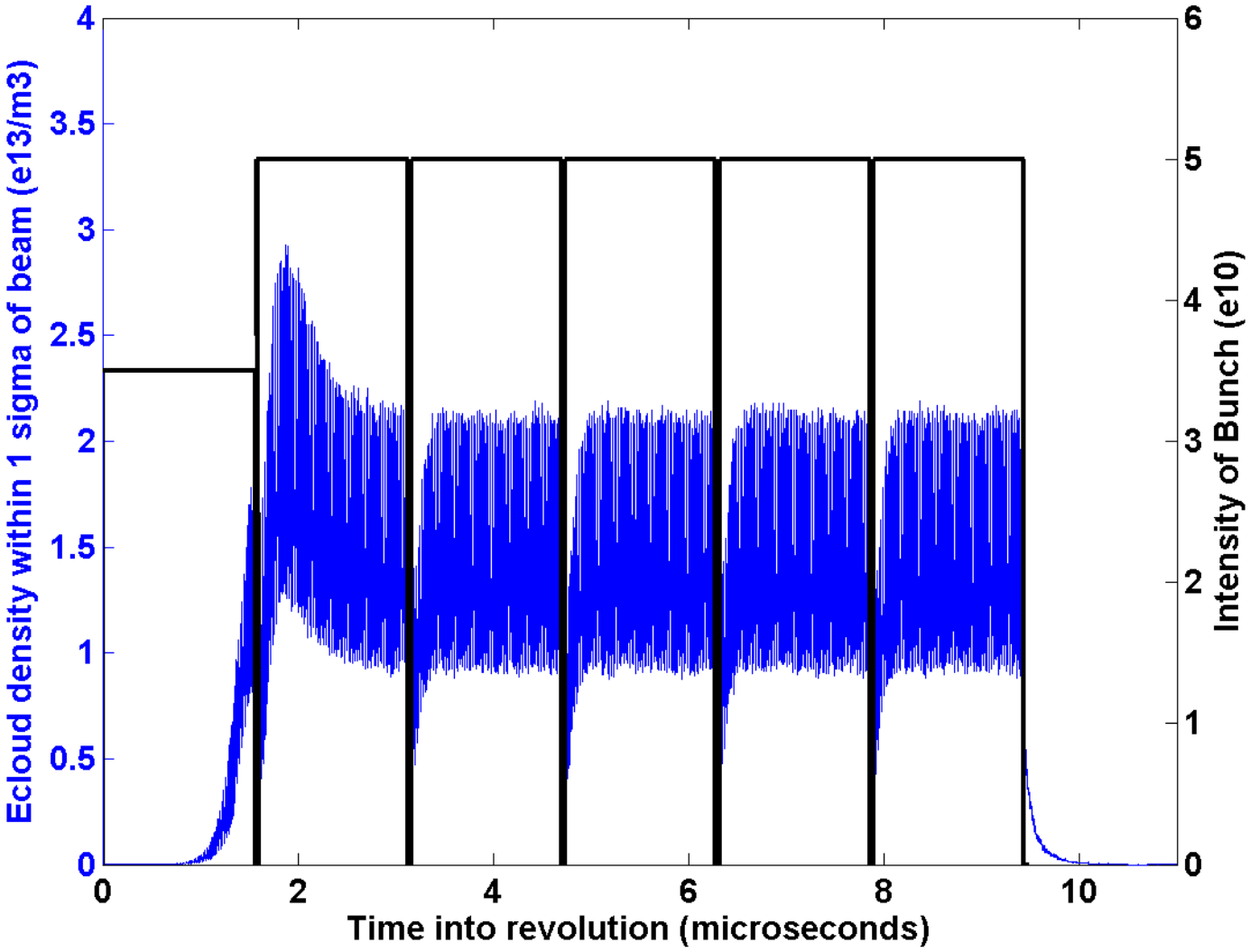


POSINST Electron Cloud Simulation

Beam Kinetic Energy (E)	8 GeV
Beam Distribution Transverse sigma (σ_x)	3 mm
Beam Distribution Longitudinal sigma (σ_z)	0.75 m
Full Bunch Intensity	5e10
Buckets per batch	84
Filled buckets per batch	82
Number of batches	6
Beampipe SEY (maximum)	2.2
Beampipe geometry	elliptical
Beampipe horizontal major axis	94 mm
Beampipe vertical major axis	44 mm
Dipole field strength	1.375 T


Ecloud density in beampipe (e13/m3)
Intensity of Bunch (e10)
Time into revolution (microseconds)
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0
1
2
3
4
5
6
0
2
4
6
8
10


Ecloud density within 1 sigma of beam (e13/m3)
Intensity of Bunch (e10)
Time into revolution (microseconds)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6
0
2
4
6
8
10


Ecloud density within 1 sigma of beam (e13/m3)
Intensity of Bunch (e10)
Time into revolution (microseconds)
0
0.5
1
1.5
2
2.5
3
3.5
4
0
1
2
3
4
5
6
0
2
4
6
8
10

Conclusions

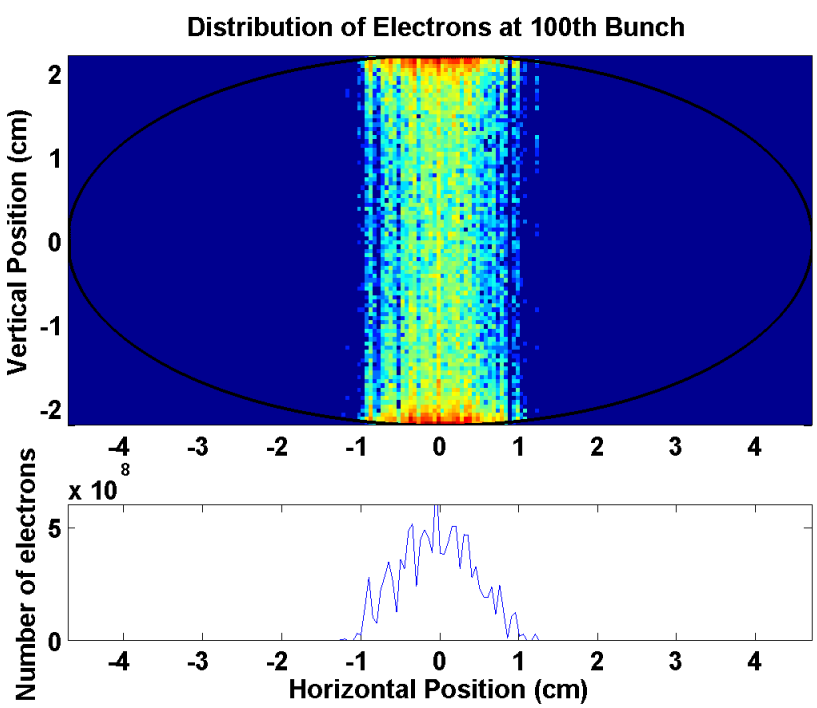
- New instability in the Recycler.
- Electron cloud measurements.
  - Strong bunch length dependence.
  - Feedback with transverse emittance.
- Commissioning the Recycler for slip-stacking.
  - Beampipe conditioning will continue.

Check out the Conference Paper!

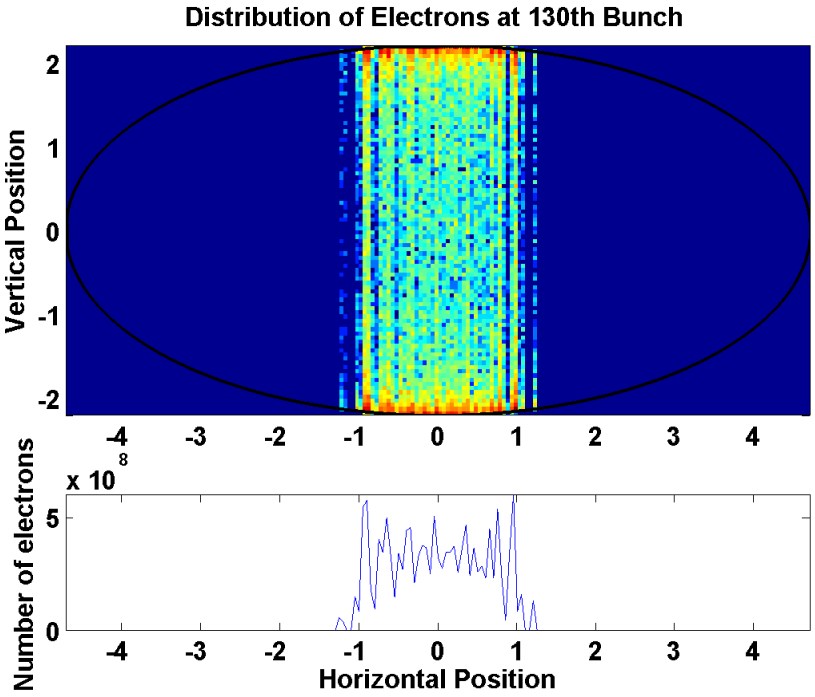
Any Questions?

Backup Slides

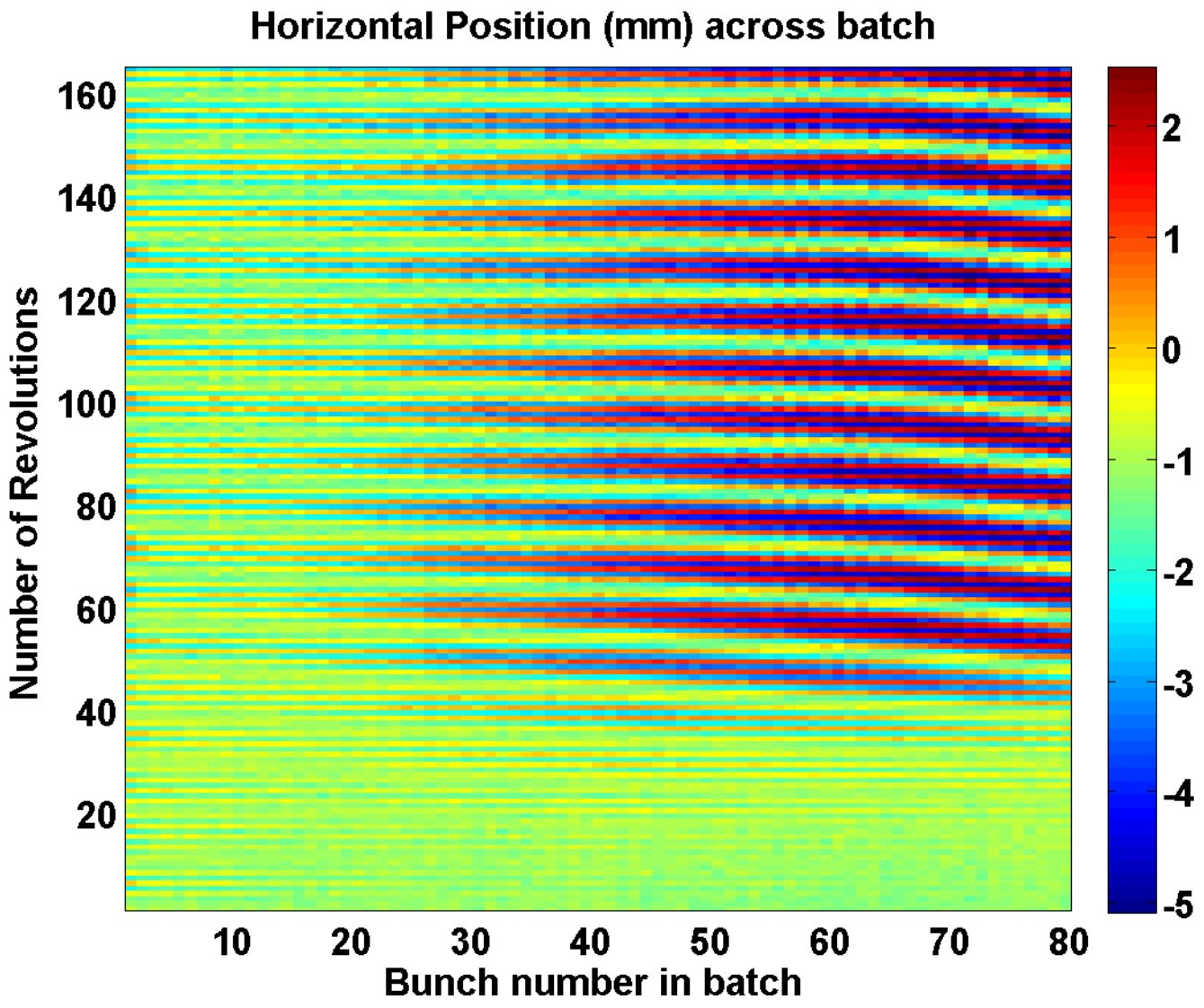
1 stripe

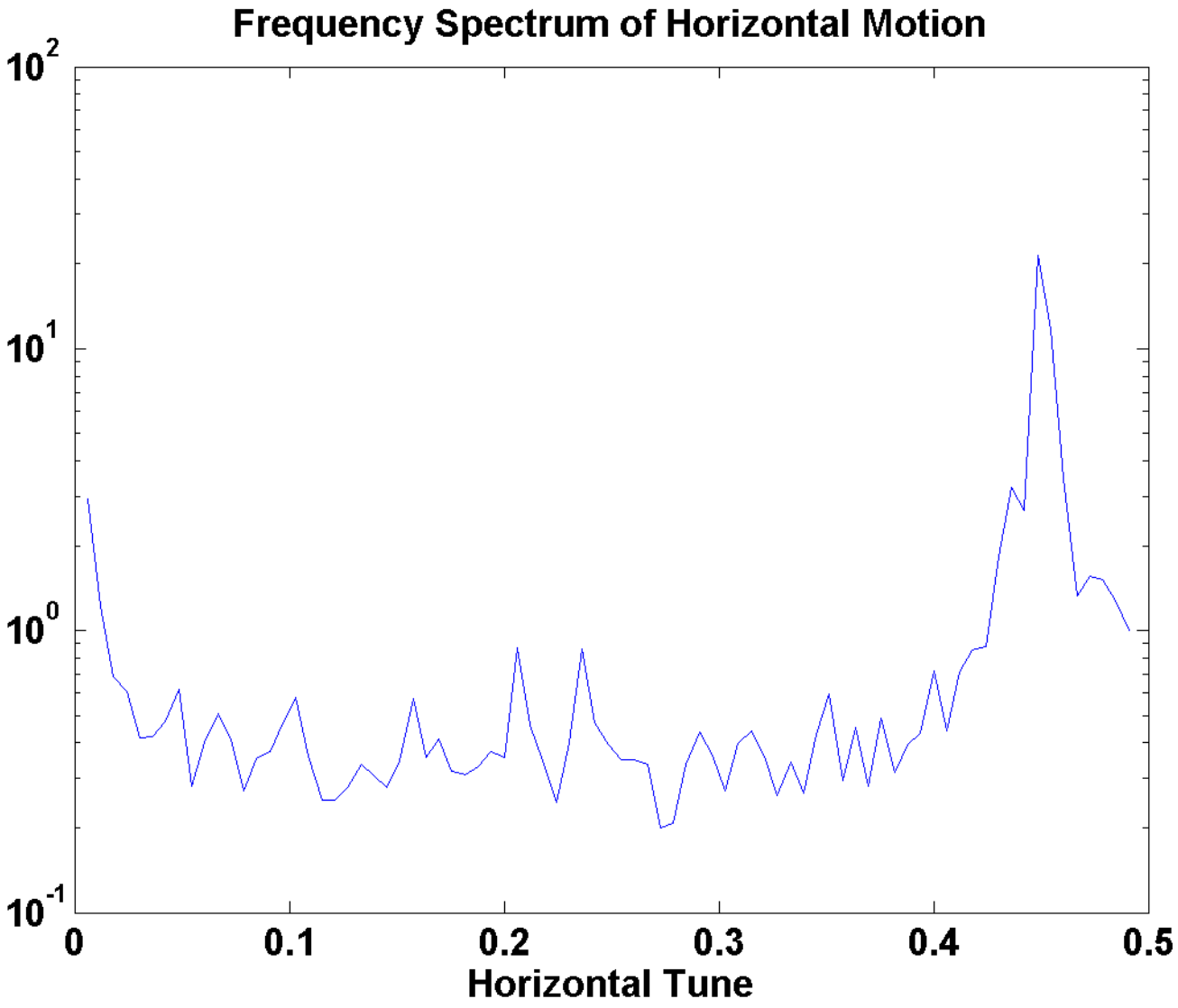


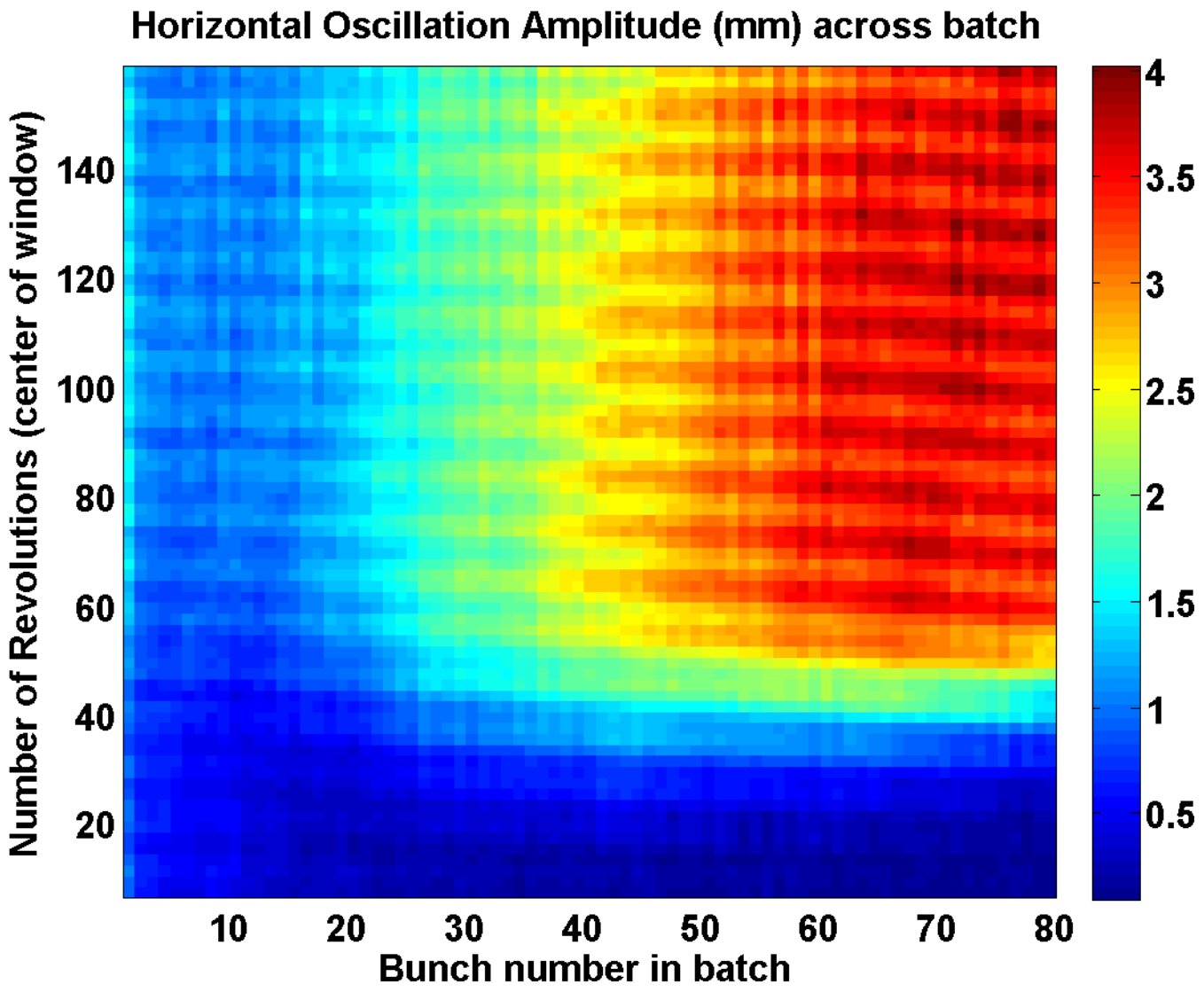
2 stripes

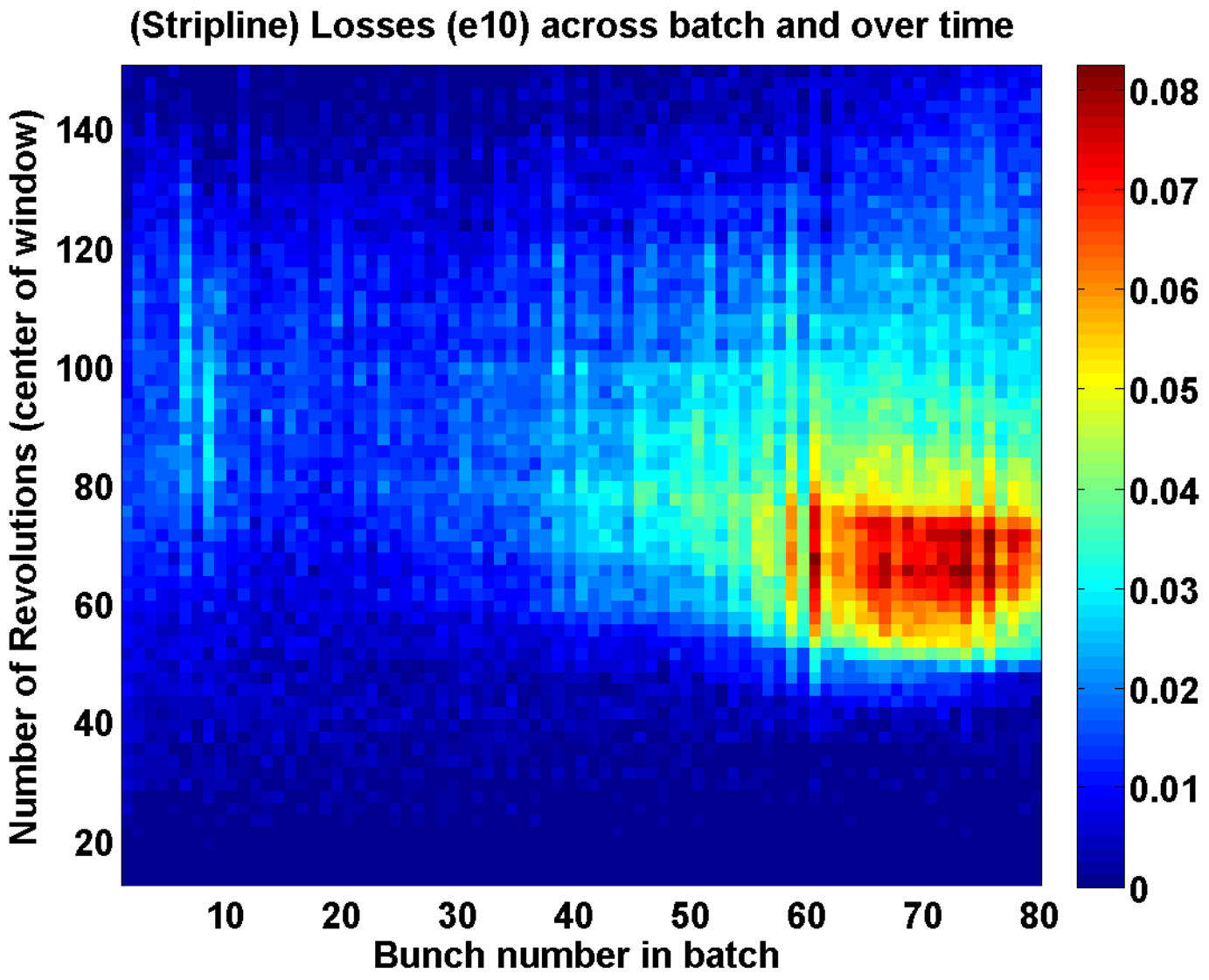


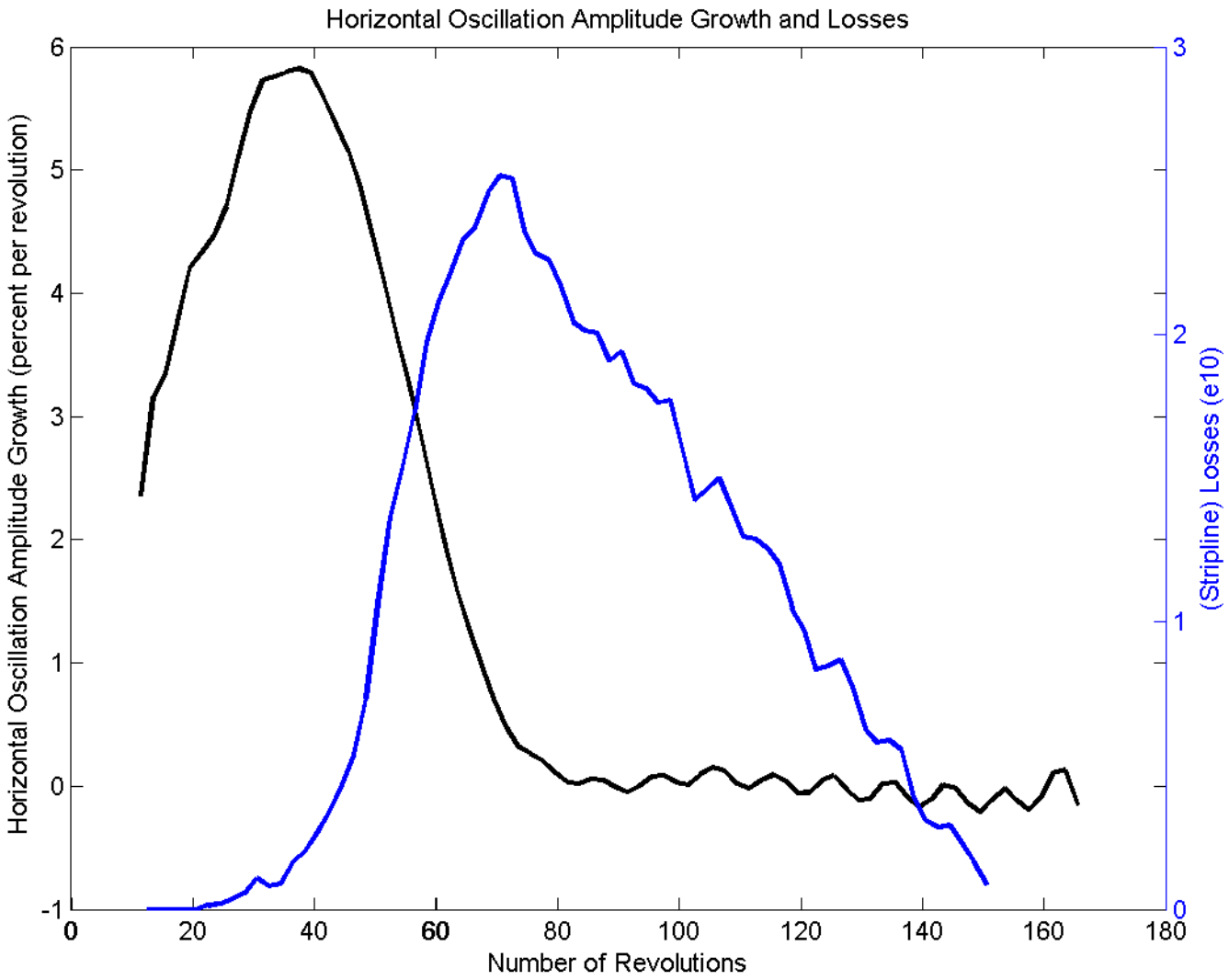
Beam Position Measurements

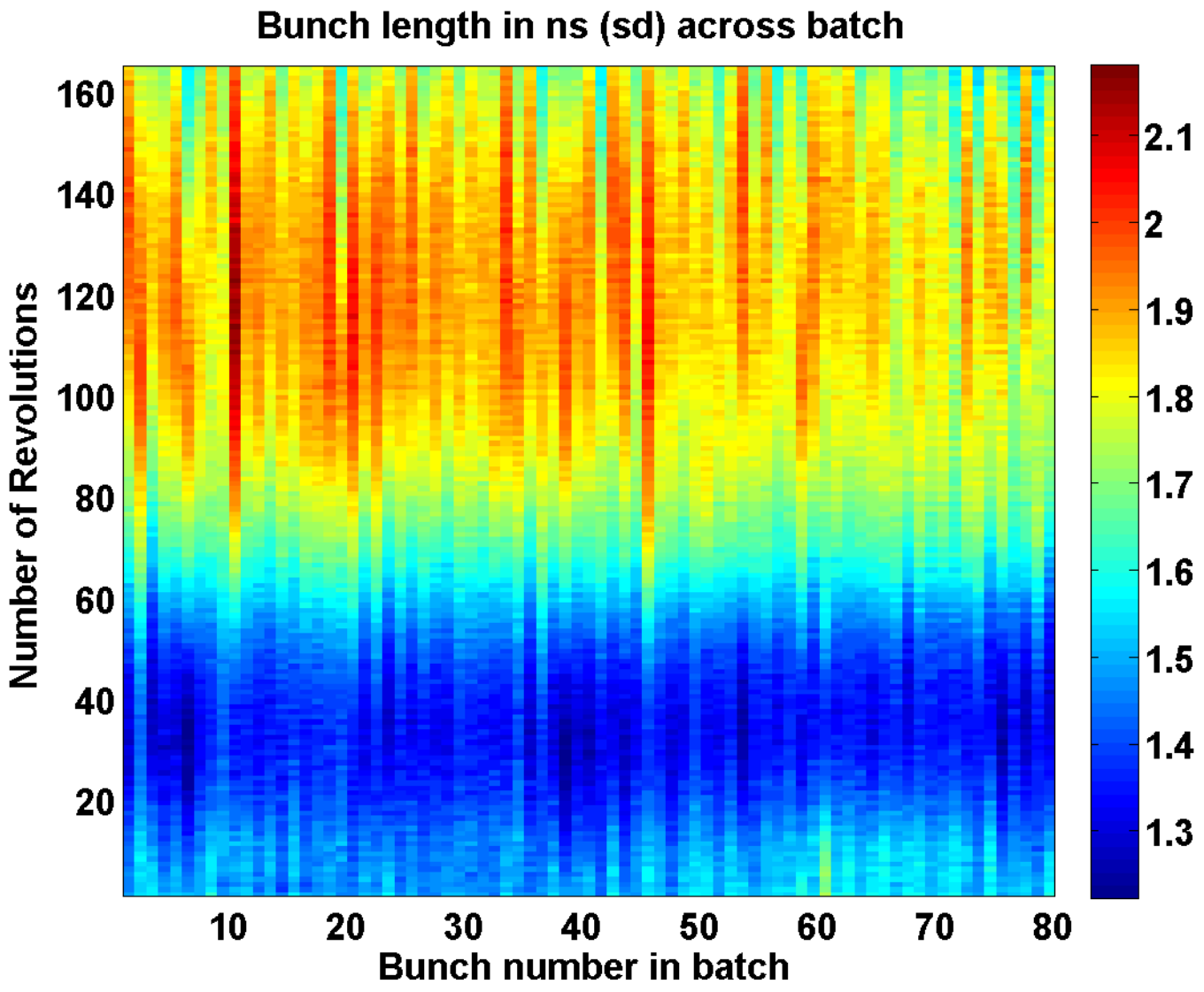

Horizontal Position (mm) across batch
Number of Revolutions
160
140
120
100
80
60
40
20
10
20
30
40
50
60
70
80
Bunch number in batch
2
1
0
-1
-2
-3
-4
-5

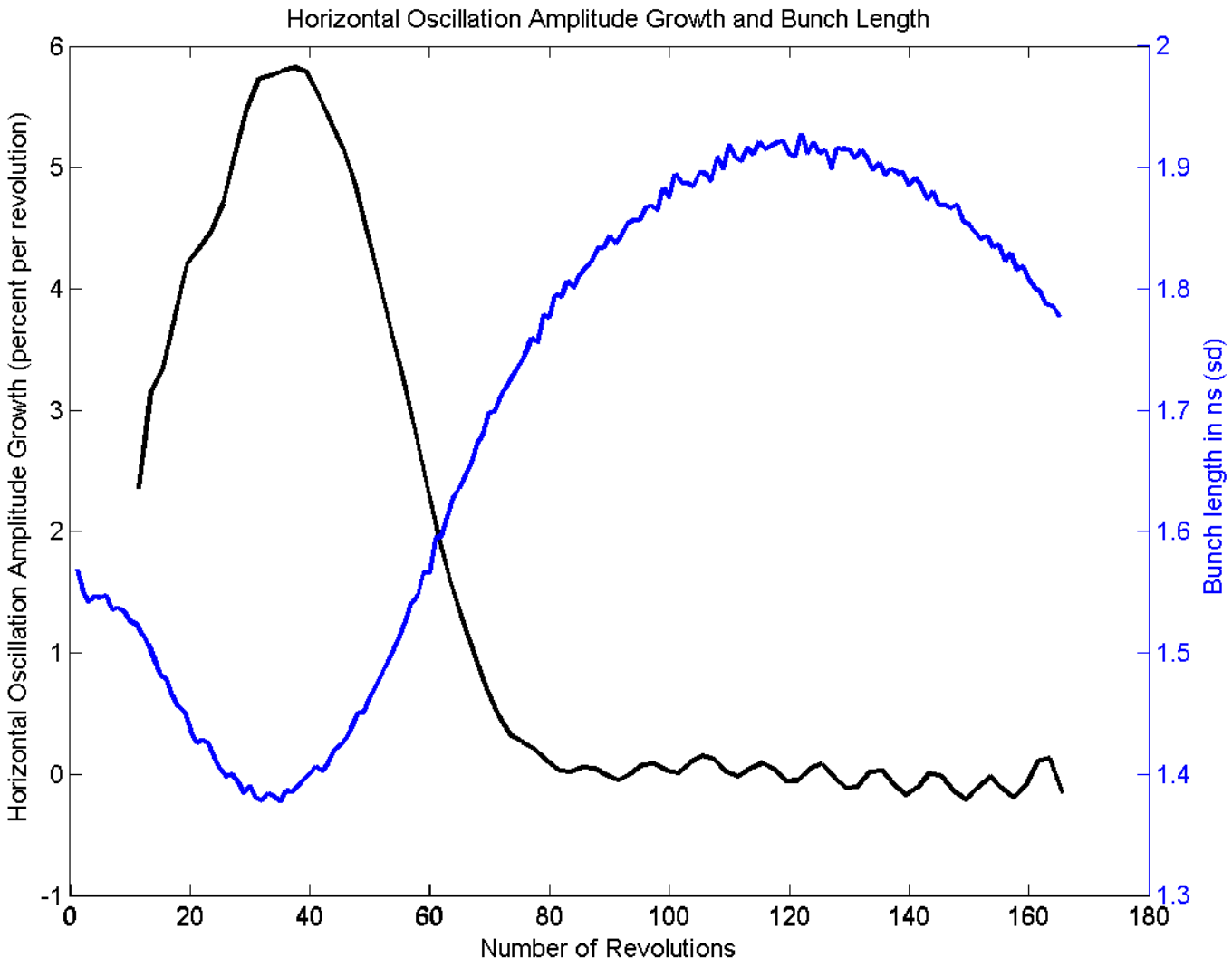

Frequency Spectrum of Horizontal Motion
10^2
10^1
10^0
10^-1
0
0.1
0.2
0.3
0.4
0.5
Horizontal Tune


Horizontal Oscillation Amplitude (mm) across batch
Number of Revolutions (center of window)
20
40
60
80
100
120
140
10
20
30
40
50
60
70
80
Bunch number in batch
0.5
1
1.5
2
2.5
3
3.5
4


(Stripline) Losses (e10) across batch and over time
Number of Revolutions (center of window)
140
120
100
80
60
40
20
10
20
30
40
50
60
70
80
Bunch number in batch
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0


Horizontal Oscillation Amplitude Growth and Losses
Horizontal Oscillation Amplitude Growth (percent per revolution)
(Stripline) Losses (e10)
Number of Revolutions
6
5
4
3
2
1
0
-1
3
2
1
0
0
20
40
60
80
100
120
140
160
180


Bunch length in ns (sd) across batch
Number of Revolutions
160
140
120
100
80
60
40
20
10
20
30
40
50
60
70
80
Bunch number in batch
2.1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3


Horizontal Oscillation Amplitude Growth and Bunch Length
Horizontal Oscillation Amplitude Growth (percent per revolution)
Bunch length in ns (sd)
Number of Revolutions
6
5
4
3
2
1
0
-1
2
1.9
1.8
1.7
1.6
1.5
1.4
1.3
0
20
40
60
80
100
120
140
160
180