ALS Orbit Stability

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BES Light Source Beam Stability Workshop

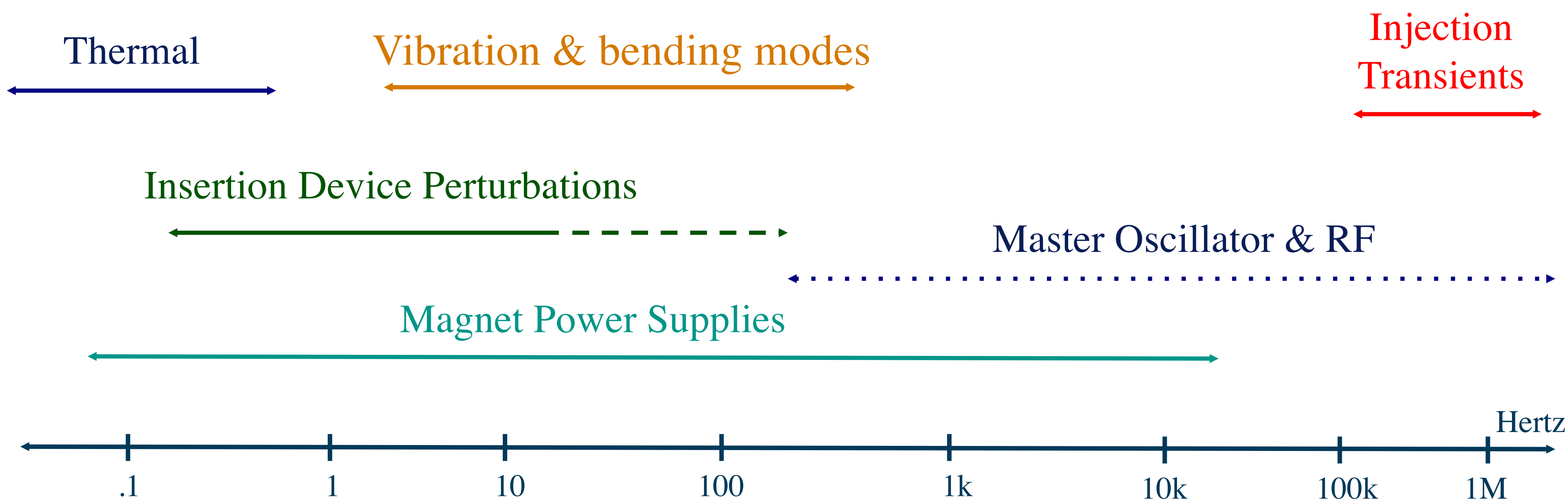
November 1, 2018

U.S. DEPARTMENT OF ENERGY | Office of Science

BERKELEY LAB

ALS

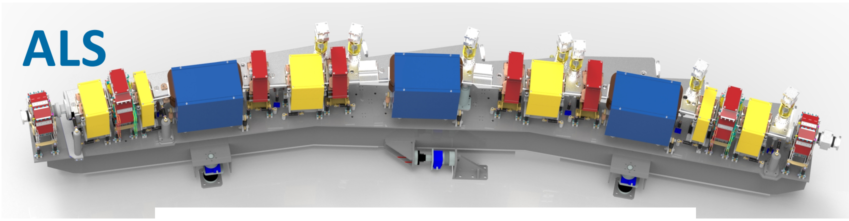
Causes of Undesirable Orbit Motions

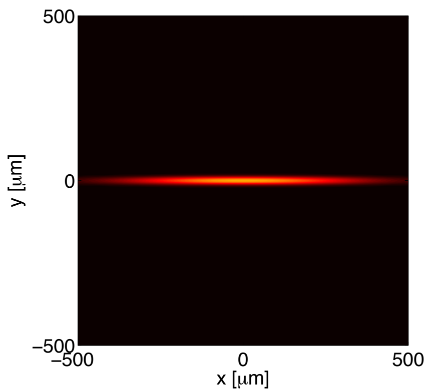


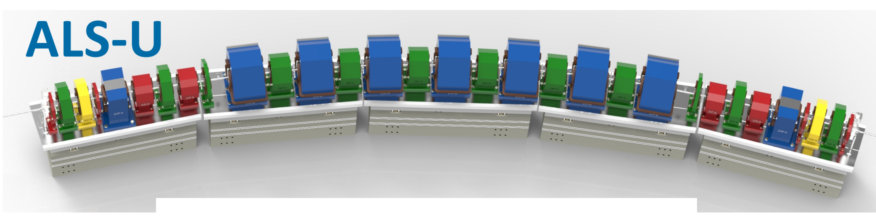
Beam Position monitors (BPMs) need to measure orbits over a large range of frequencies

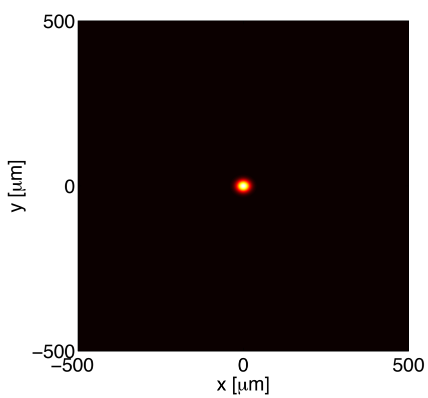
As well as, a range of beam currents, and fill patterns (single to multi-bunch fills)

Orbit Stability Goal (ALS and ALS-U)









Storage Ring	ALS-U	ALS
Electron Energy	2.0 GeV	1.9 GeV
Horizontal Emittance (full coupling)	<75 pm (50 pm stretch goal)	2 nm
Vertical Emittance	<75 pm (full coupling)	30 pm
ID Beam Size (x/y)	<14 µm / <14 µm	251 / 10.4 µm
Bend Beam Size (x/y)	<5 µm / <10 µm	40.3 / 7.1 µm (Center bend)

- ALS has 7 to 10 µm vertical beam sizes

  ALS-U will have 5 to 14 µm beam sizes in both planes
- The requirement is 1/10 the beam size

  -> 0.5 µm @ the Bends, 1.4 µm @ the IDs
- The goal is 1/20 the beam size

  -> 0.25 µm @ the Bends, 0.7 µm @ the IDs

➔ **ALS and ALS-U have similar requirements**

➔ **The BPM development goal is 200 nm RMS from a few days to 10 kHz**

ALS and ALS-U BPM Needs

Recently built 158 BPMs for ALS

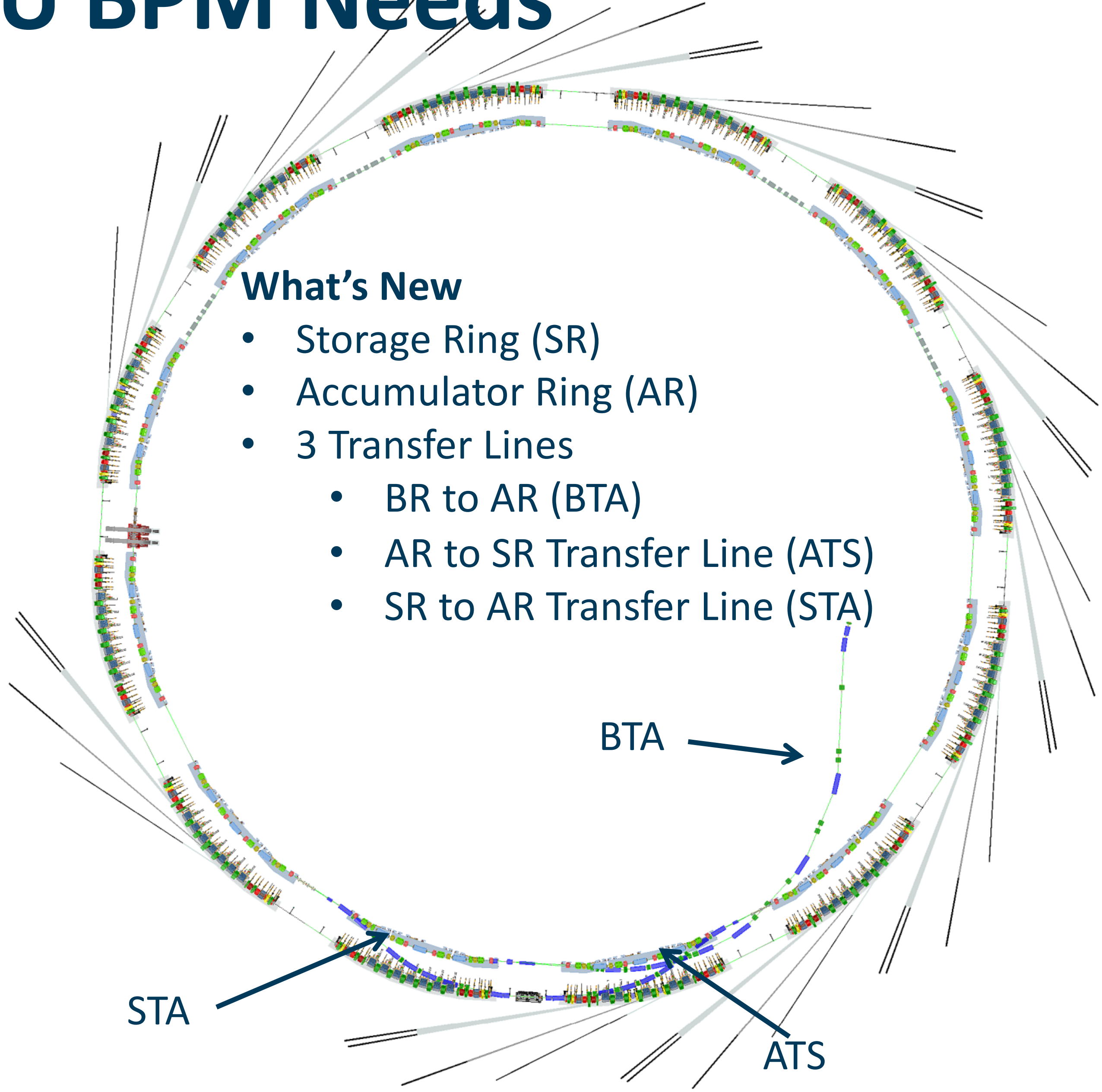
- **114 Storage Ring**
- **37 Injector**
- **And a few spares**

ALS-U will need

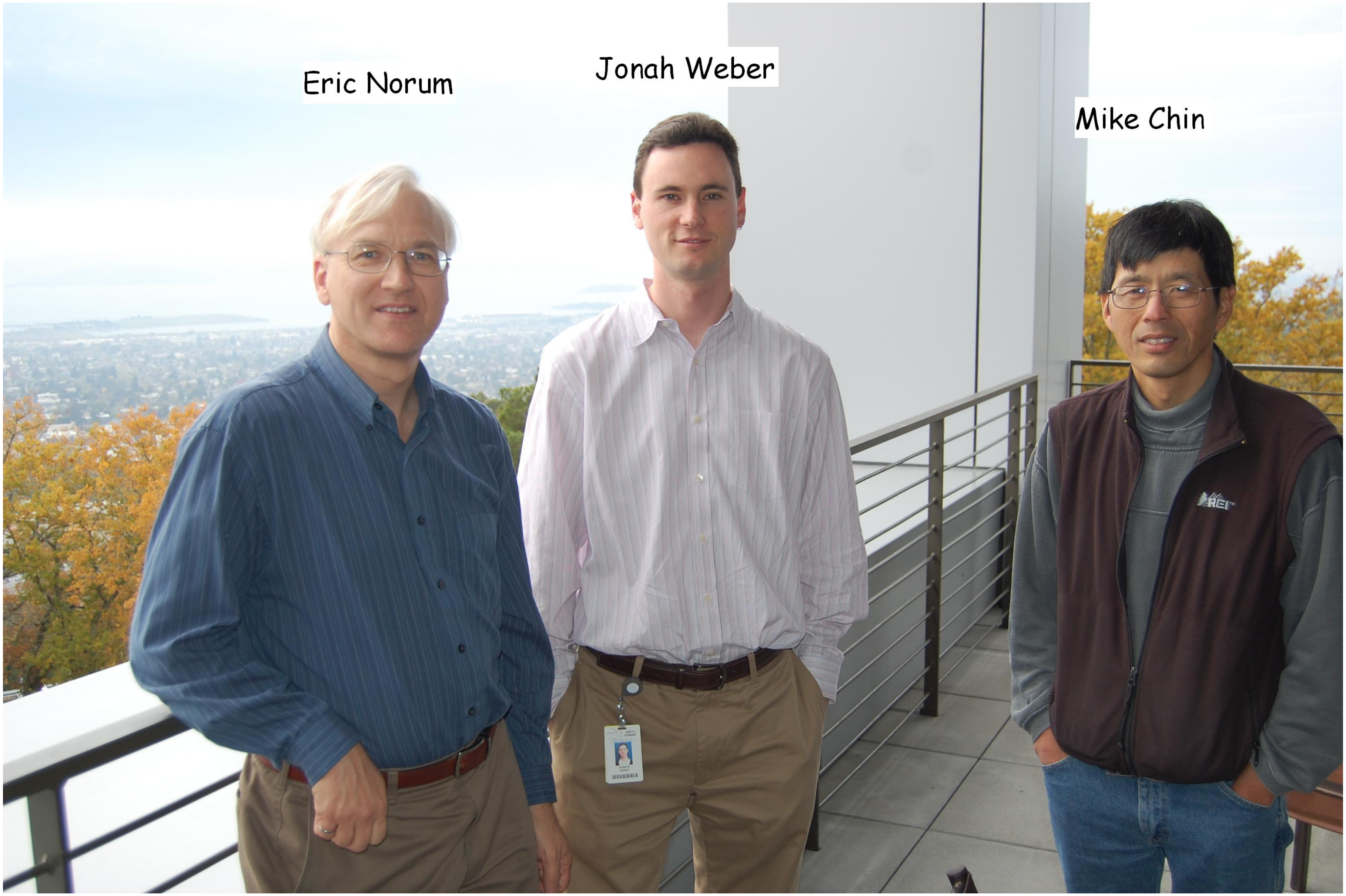
- **192 in the storage ring (16 /sector)**
- **72 in the accumulator ring (6 /sector)**
- **~20 in the transfer lines**

What's New

- Storage Ring (SR)
- Accumulator Ring (AR)
- 3 Transfer Lines
  - BR to AR (BTA)
  - AR to SR Transfer Line (ATS)
  - SR to AR Transfer Line (STA)



ALS Instrumentation Group



Missing: Rick Lellinger who coordinates purchases, fabrication, and installation

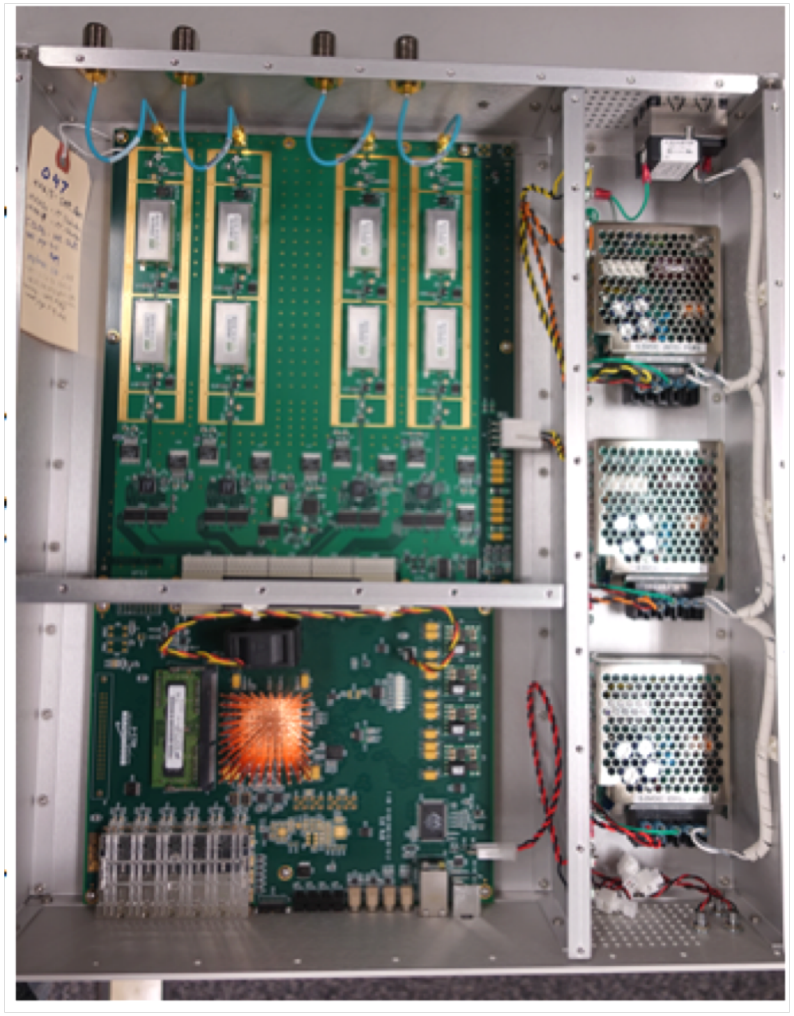
The NSLS-2 BPM

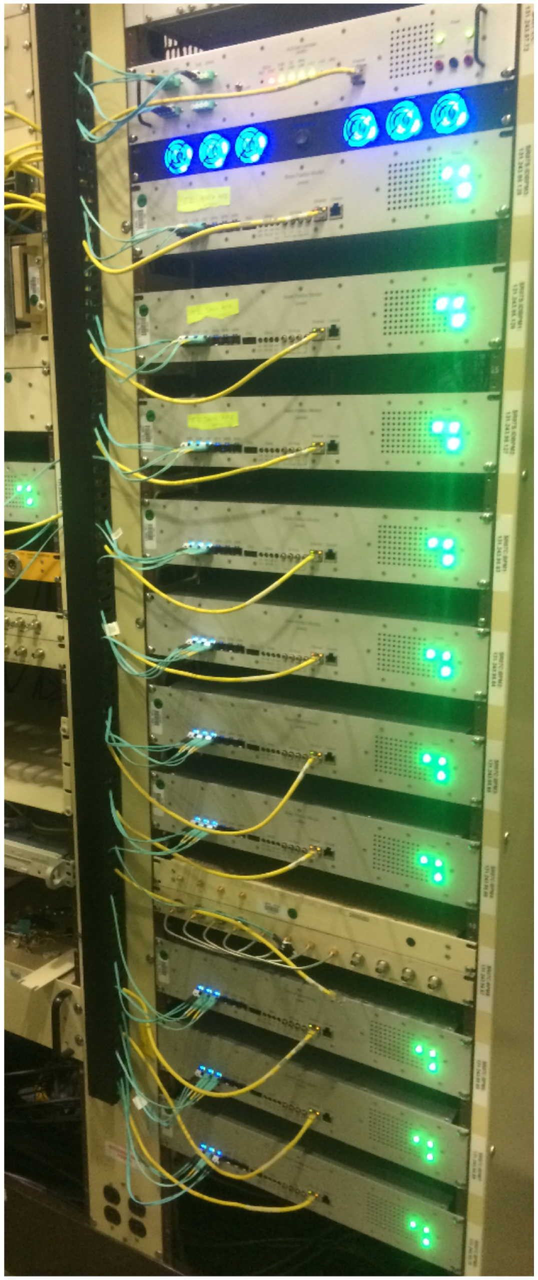
Storage Ring Thermal Racks Regulated to +-0.1C

- **BNL started a new BPM development for the NSLS-II project.**
- **We helped test this BPM at ALS before NSLS-II was built (similar RF frequencies)**
- **We leveraged this development for the new ALS BPM**
- **ALS doesn't have temperature controlled racks, so we further developed the pilot tone compensation method that NSLS-II started.**

We are very grateful to the NSLS-II team for their openness and expertise!
Kurt Vetter, Joe Mead, Kiman Ha, Yuke Tian, Marshall Maggipinto, Joe Delong, Al Dellapenna, Danny Padrazo, … . And others including Jim Sebek at SSRL.

ALS BPM Development

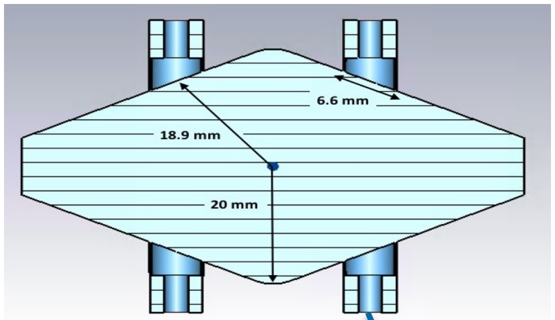




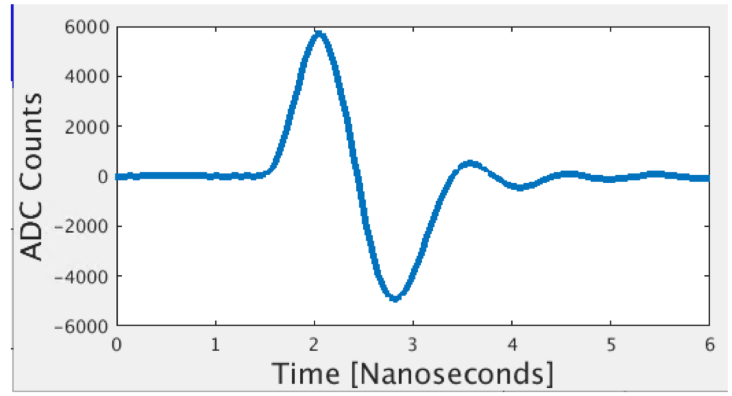
- Identical DFE as the NSLS-II BPM
- The AFE was modified for ALS

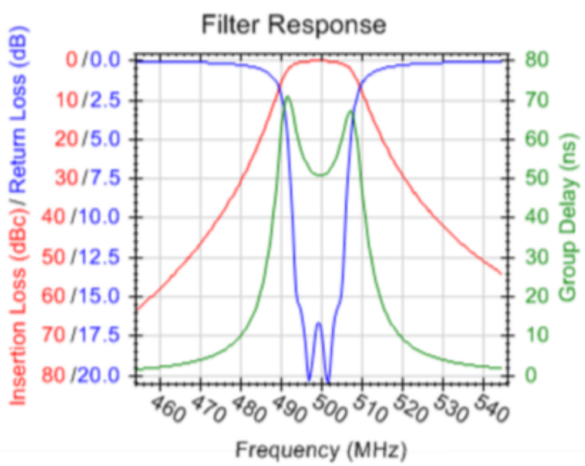
Signal Domains

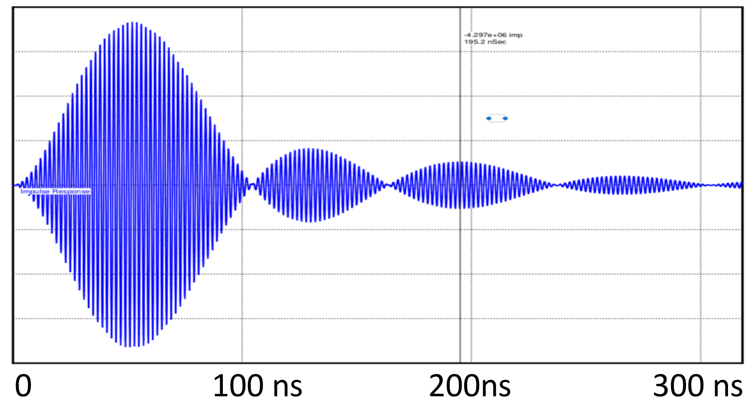
ALS Arc Chamber



Button + Cable + 800MHz Lowpass

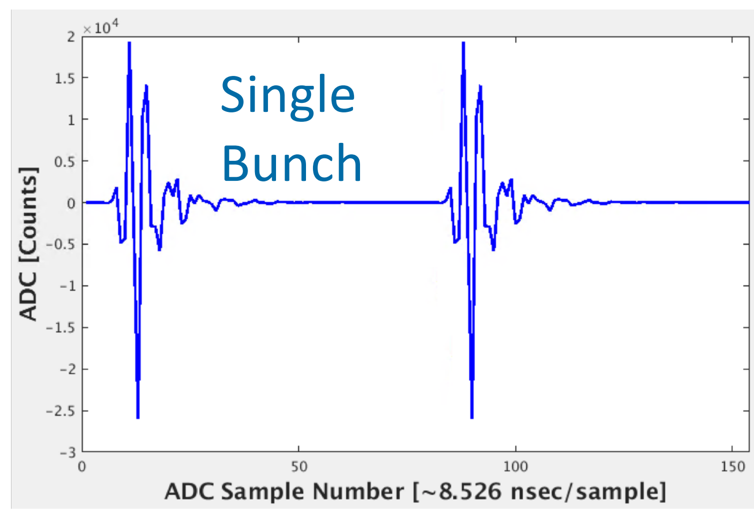






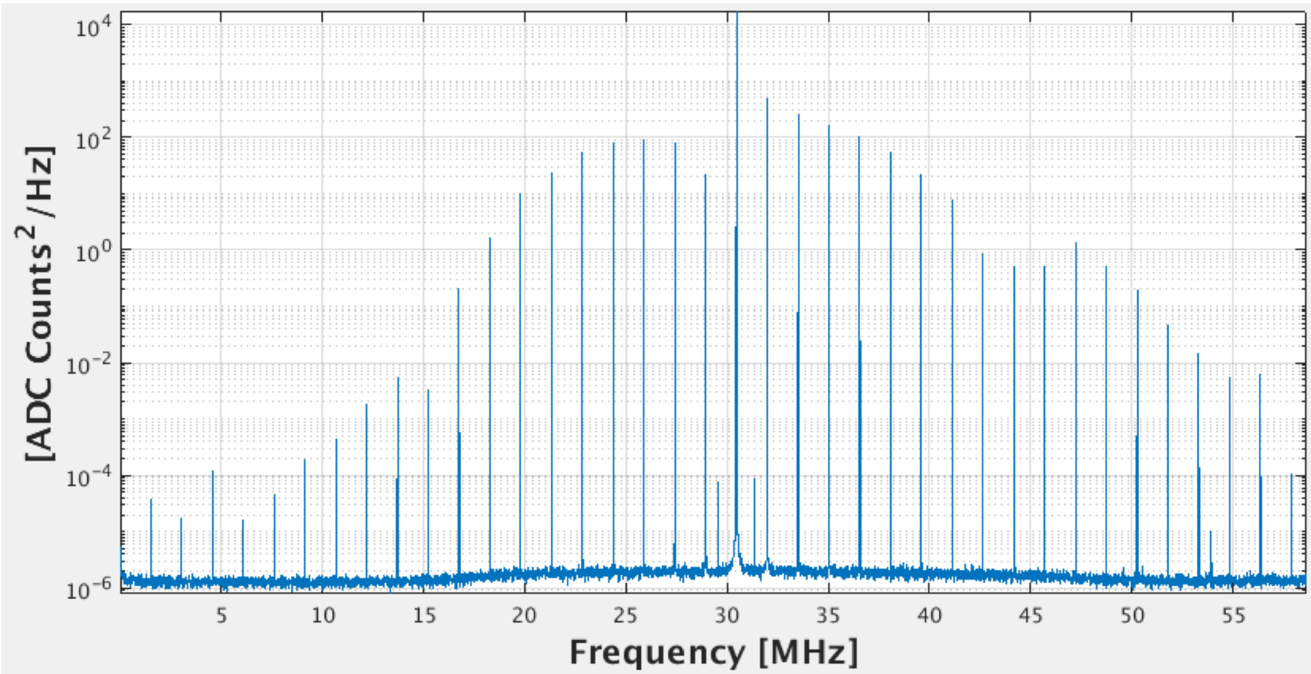
ADC

~117 MHz

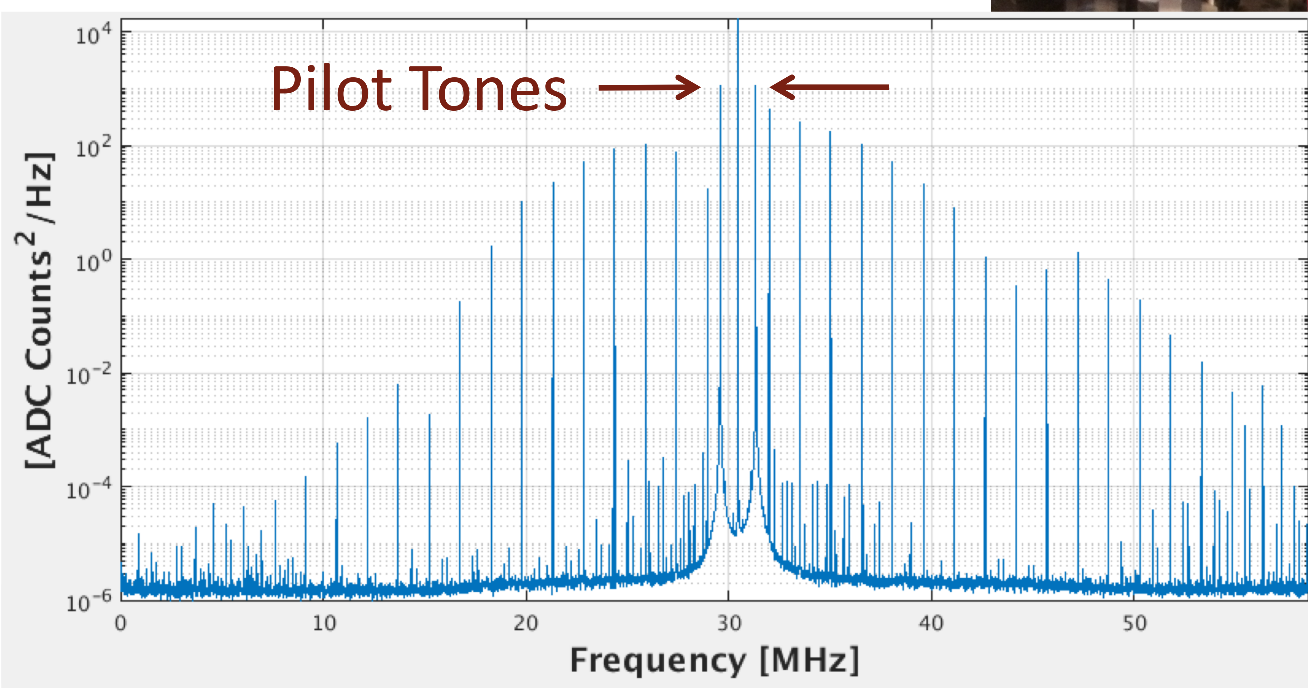


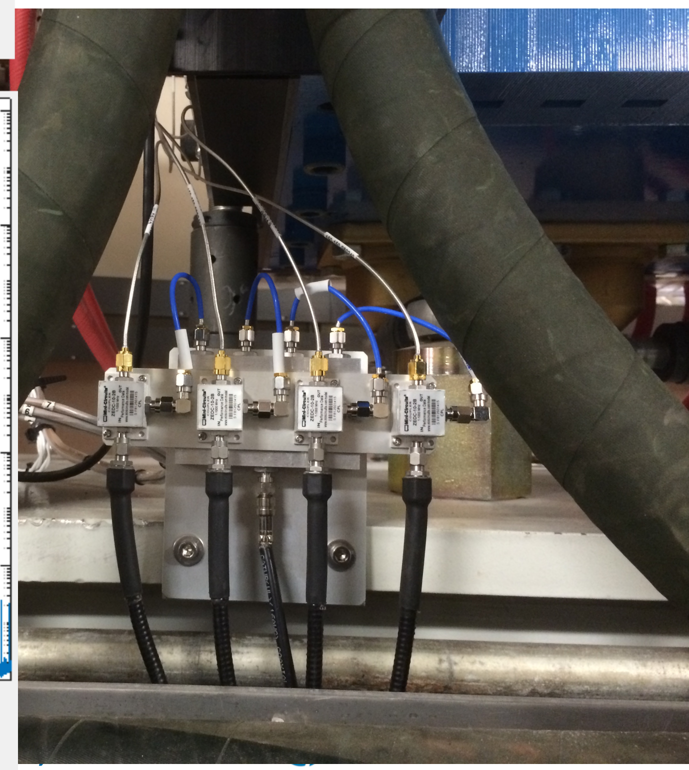
ALS arc sector BPM sensitivity is 6.25 % / mm

BPM ADC Spectrum w/ & w/o pilot tone



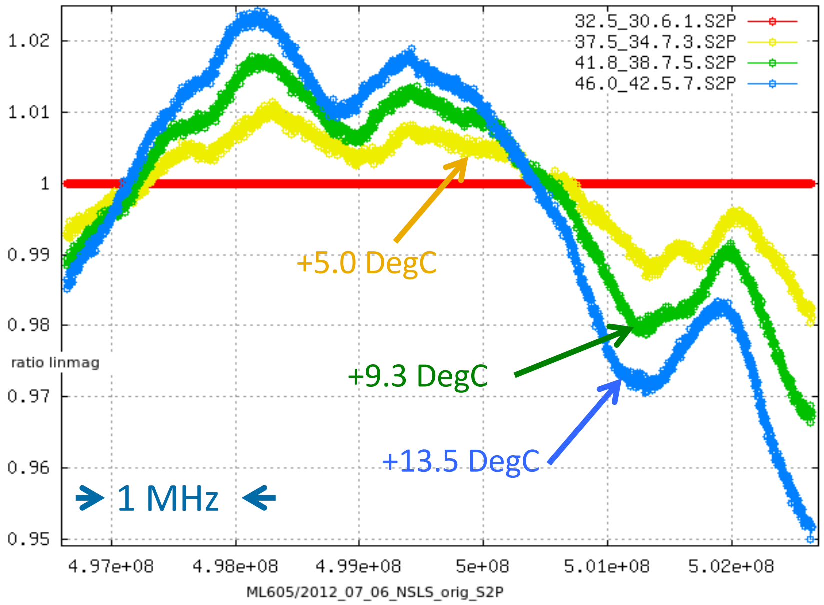
Pilot tone combiner was installed in the tunnel for temperature stability.



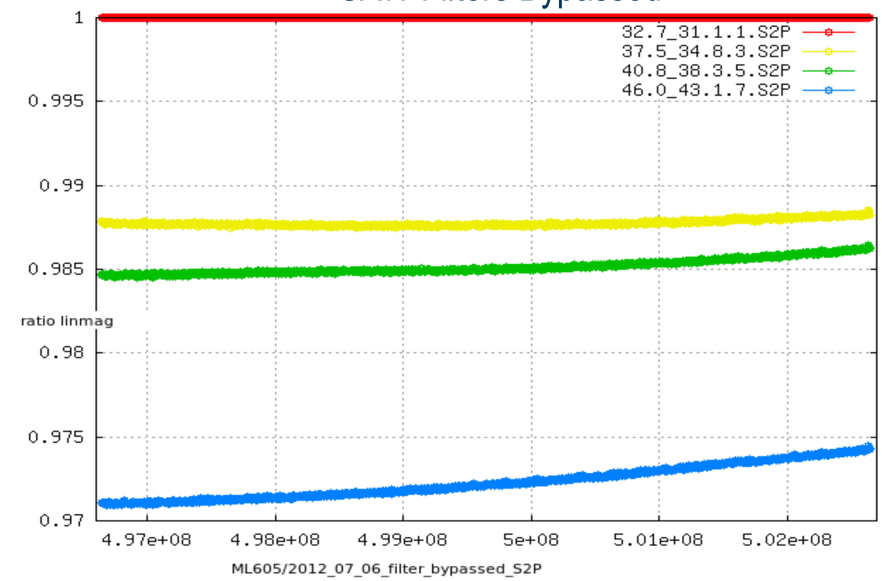


SAW Filter Thermal Analysis

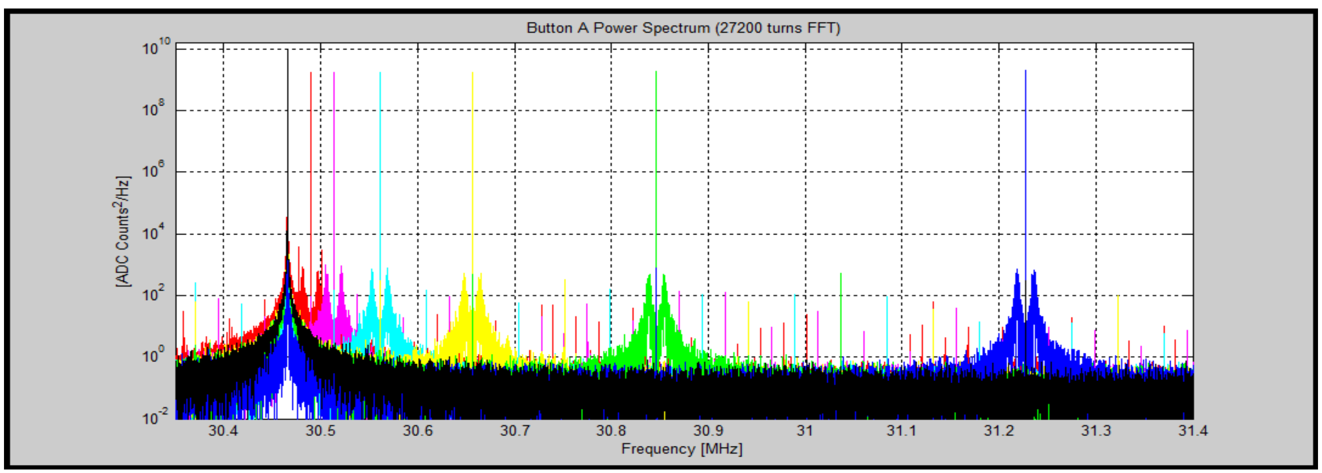
Normal BPM Channel with SAW Filters



SAW Filters Bypassed



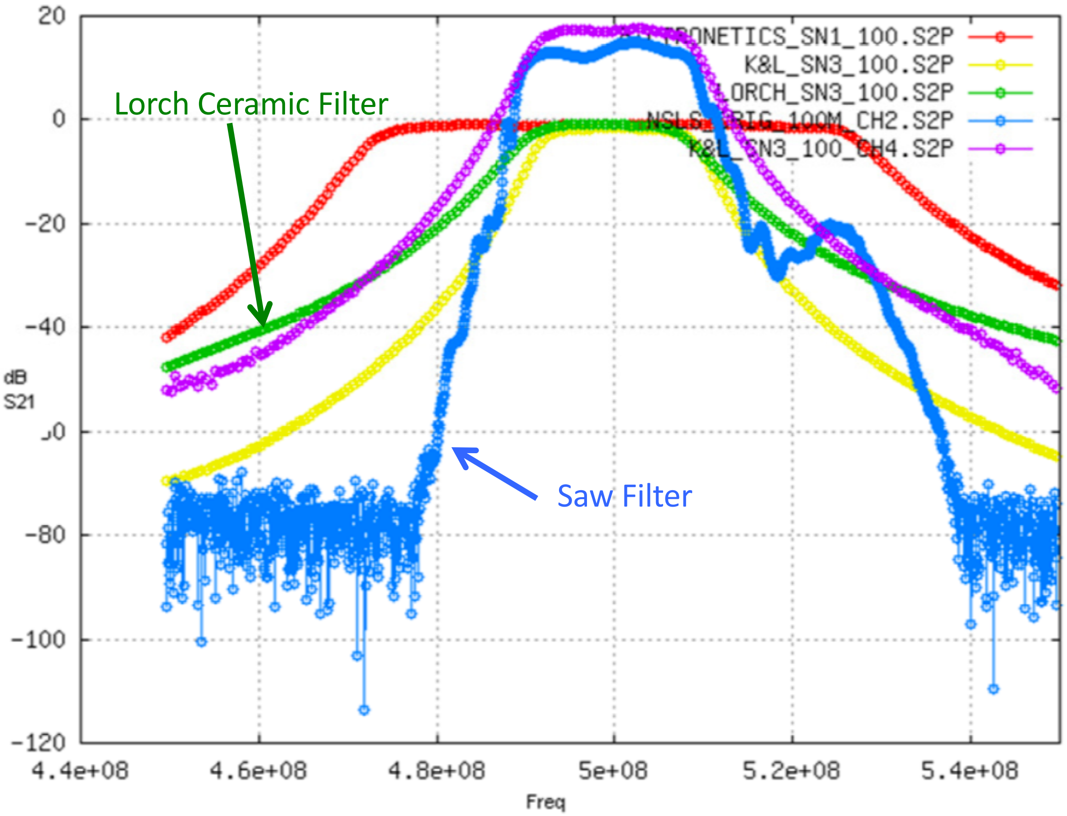
Temperature introduces a relatively curvy response in the transfer function. This indicates that a pilot tone correction can only work if the tones are close to the RF frequency. In fact, a pilot tone at +2 MHz from at RF (~499.645 MHz) would indicate that the system gain goes down with temperature, whereas at RF the gain goes up.

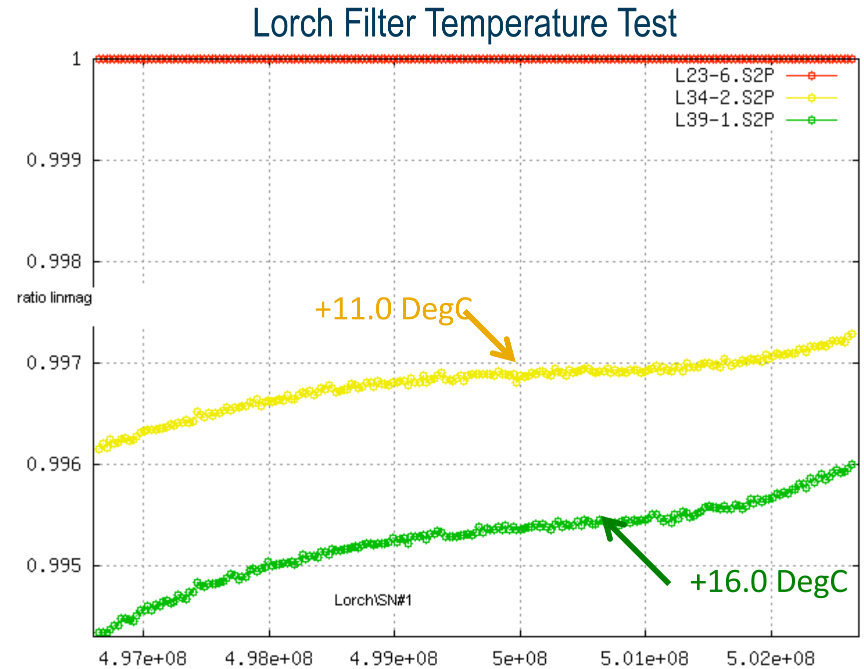


RF (blk) + calibration tone at 1/64, 1/32, 1/16, 1/8, 1/4, 1/2 a revolution harmonic.

M. Chin

Bandpass Filter Study





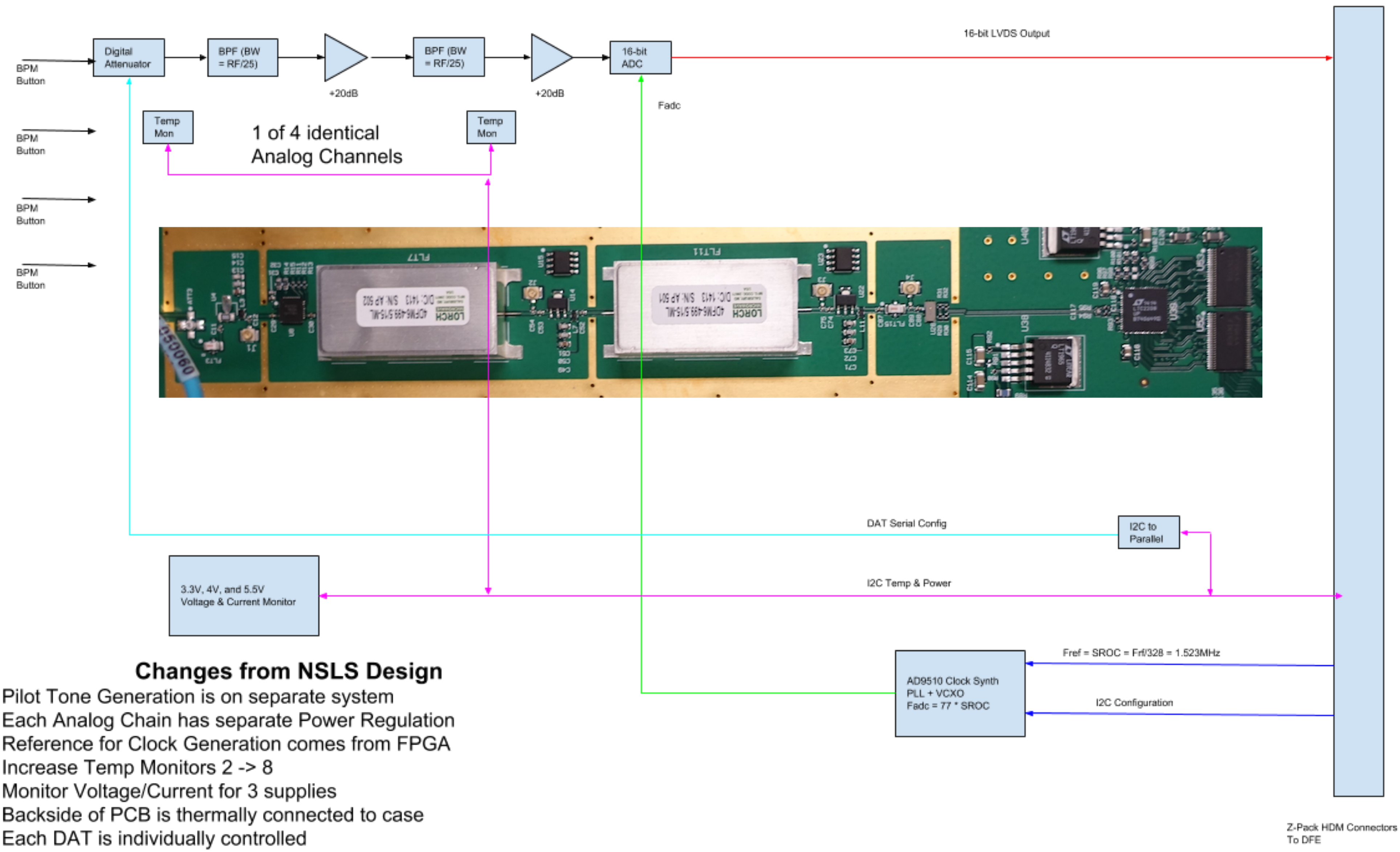
The ceramic filter had an improved linear response with temperature change

- **We original chose the Lorch ceramic filter (assembled from 4 ceramic blocks)**
- **Then we change to a mono-block ceramic filter from CTS**

M. Chin

BPM AFE Design Changes from NSLS2

AFE Block Diagram Simplified



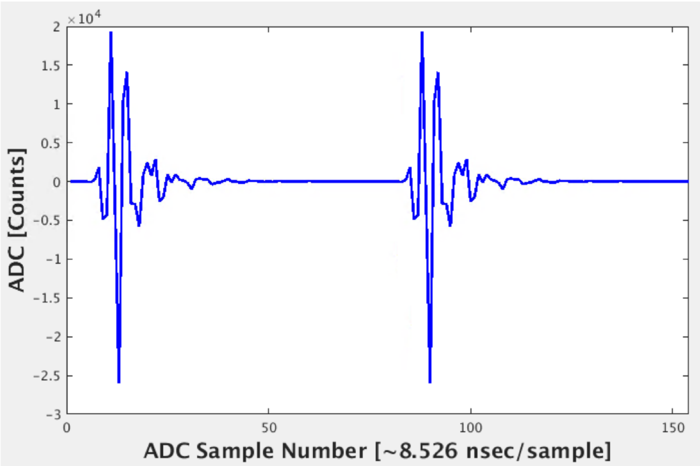
Changes from NSLS Design

Pilot Tone Generation is on separate system
Each Analog Chain has separate Power Regulation
Reference for Clock Generation comes from FPGA
Increase Temp Monitors 2 -> 8
Monitor Voltage/Current for 3 supplies
Backside of PCB is thermally connected to case
Each DAT is individually controlled
SAW BPFs changed to Ceramic

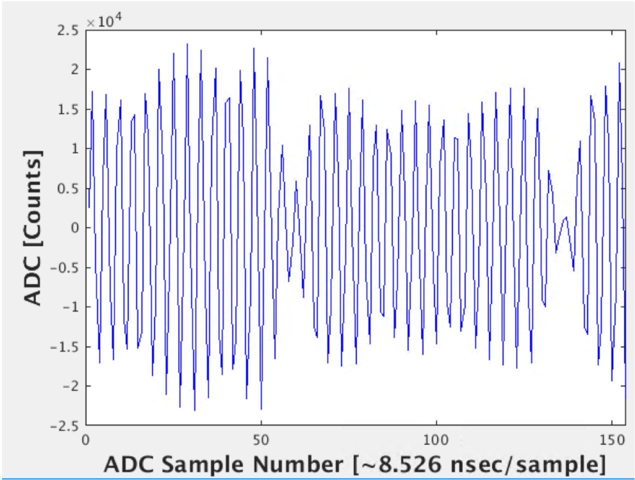
M. Chin

Parameters for the SR and Booster

Parameter	SR	BR
Circumference [m]	196.8	75
Harmonic Number	328	125
RF Frequency [MHz]	499.6472	499.6472
Revolution frequency [MHz]	1.5233	3.9972
Samples per turn	77	29
Sample Frequency [MHz]	117.297	115.918
Sample period [nsec]	8.525	8.627
Turns in an FA sample	152	380
FA [kHz]	10.022	10.526
SA [Hz]	10.022	



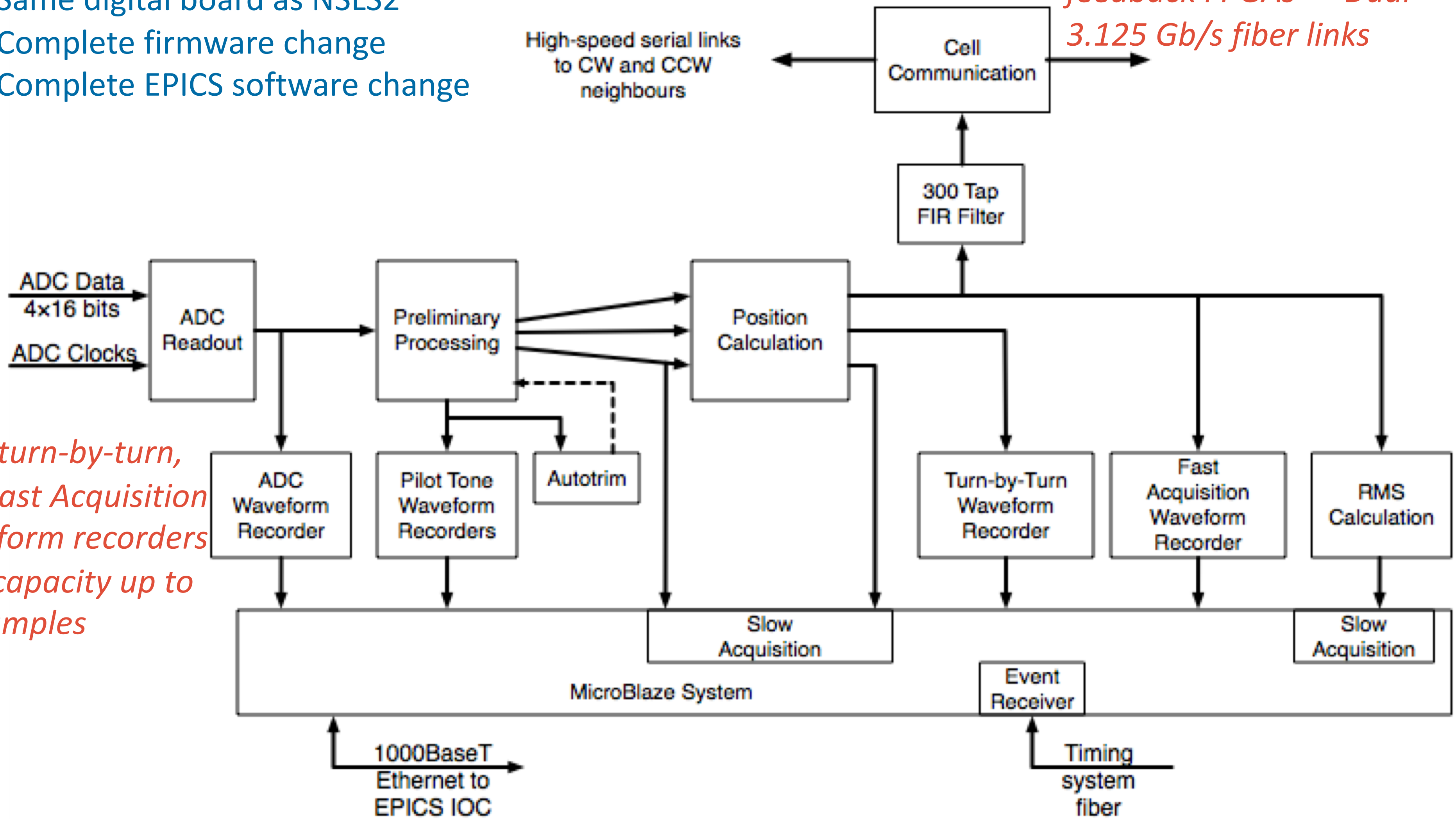
Single Bunch Fill



Multi-Bunch Fill

BPM Firmware

- Same digital board as NSLS2
- Complete firmware change
- Complete EPICS software change



'Fast Acquisition: ~10 kHz positions to fast orbit feedback FPGAs — Dual 3.125 Gb/s fiber links

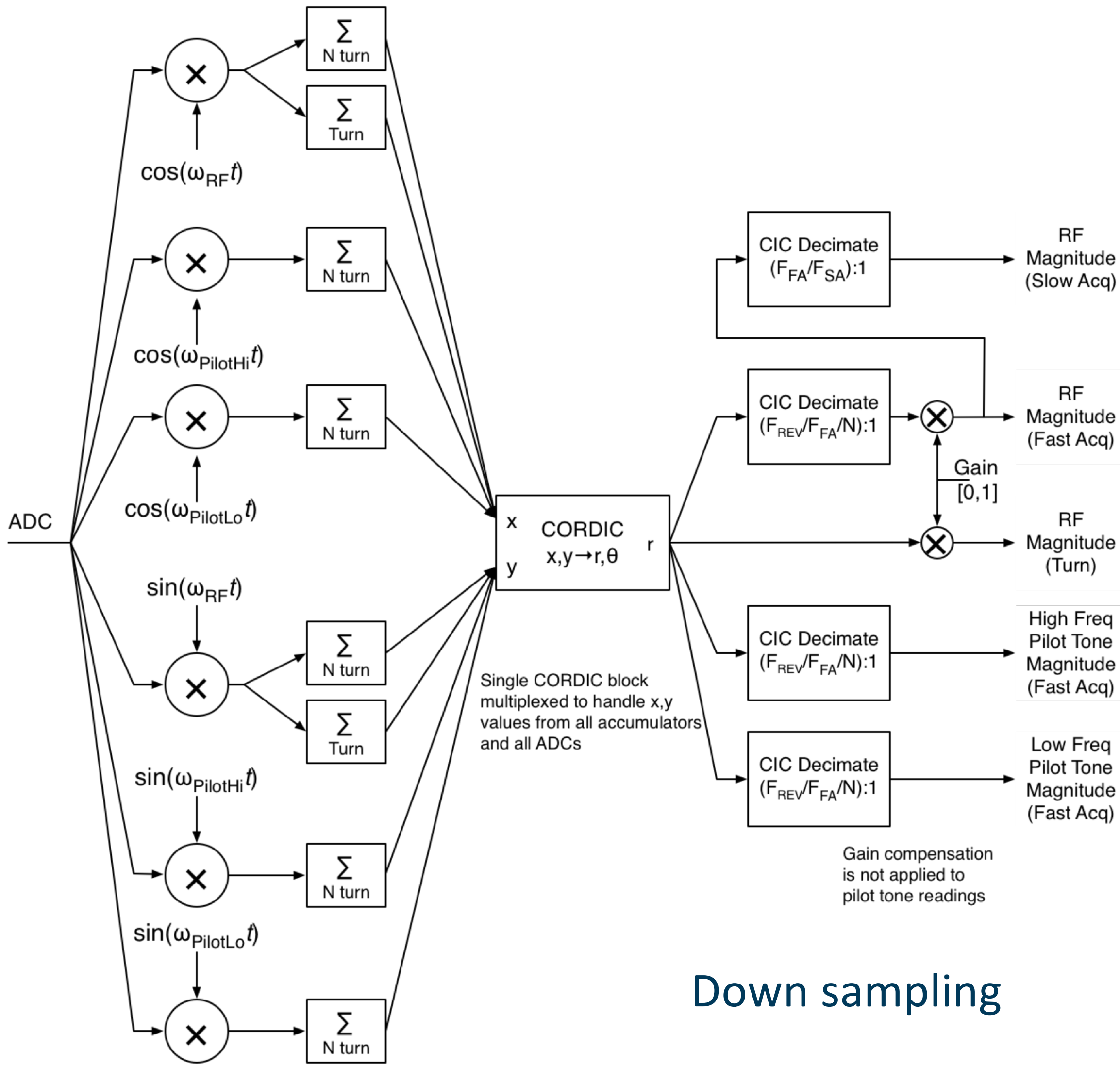
ADC, turn-by-turn, and Fast Acquisition waveform recorders with capacity up to 2^{24} samples

Slow Acquisition (~10 Hz): positions to EPICS-based orbit feedback

Acquisition clocks and triggers synchronized ALS timing system

E. Norum

BPM Firmware: Preliminary Processing Block

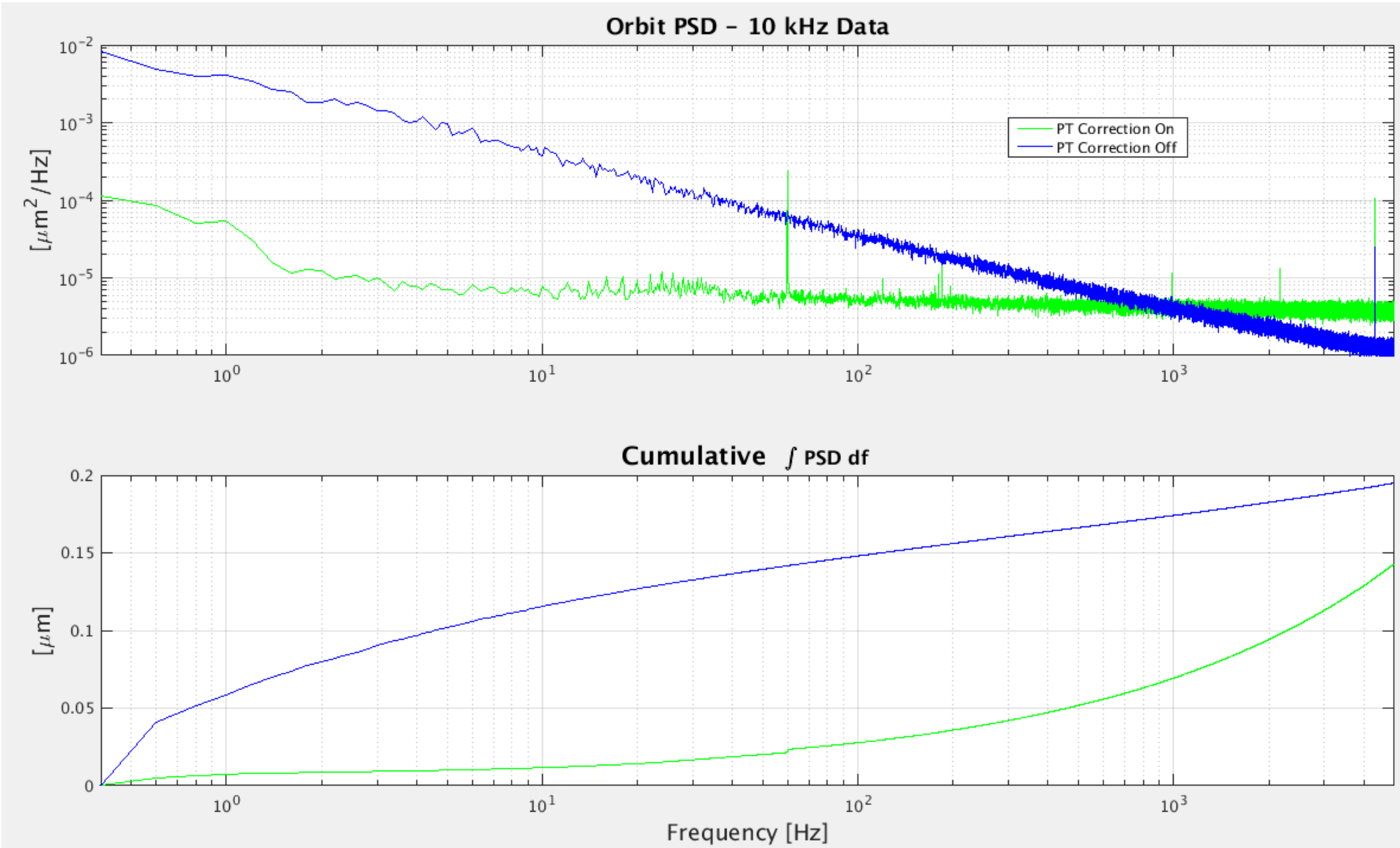


Down sampling

Synchronous Demodulation
(presently N = 19)

E. Norum

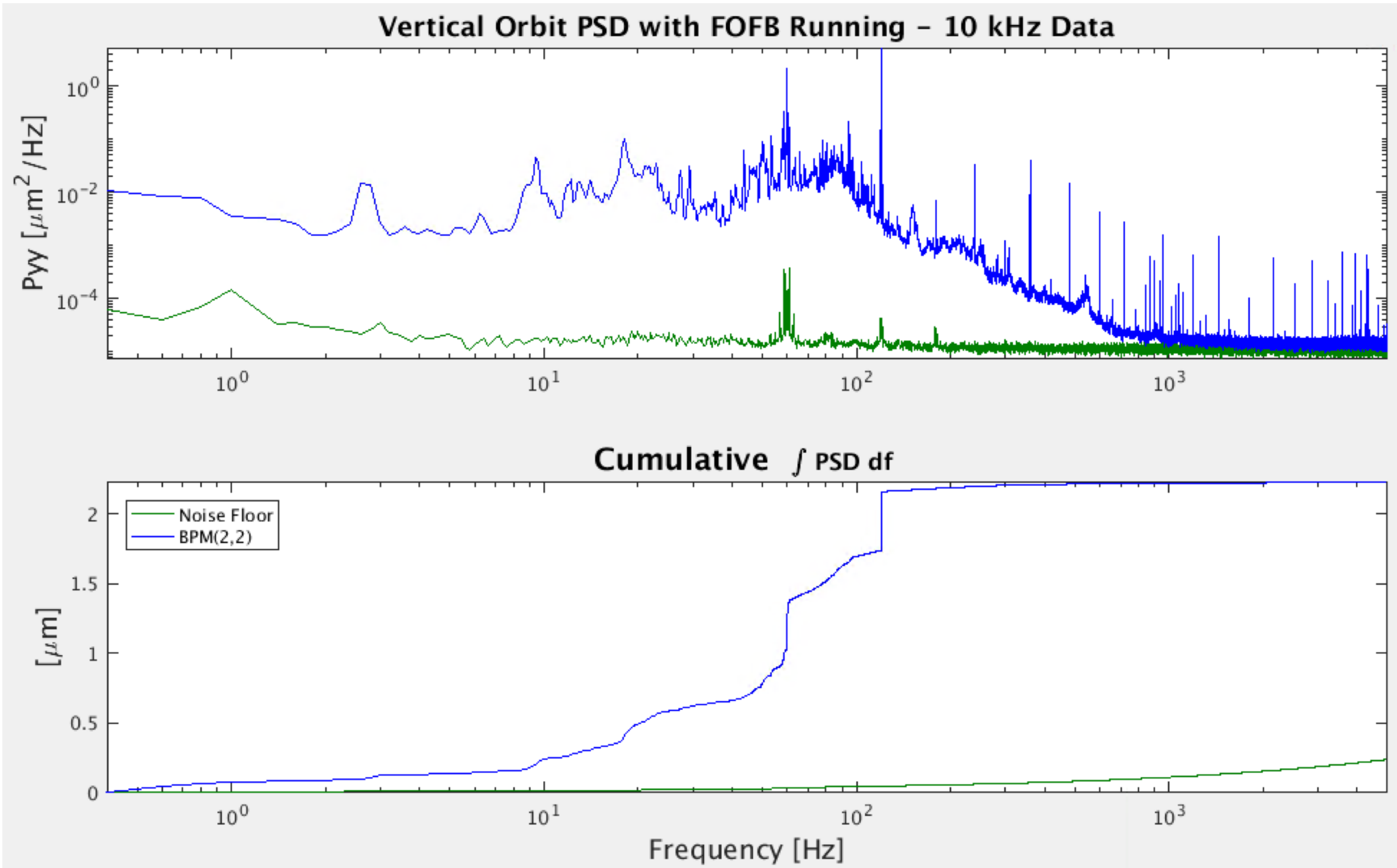
BPM Noise Floor Measurements



Measure setup: one button signal split 4 ways to the BPM inputs.

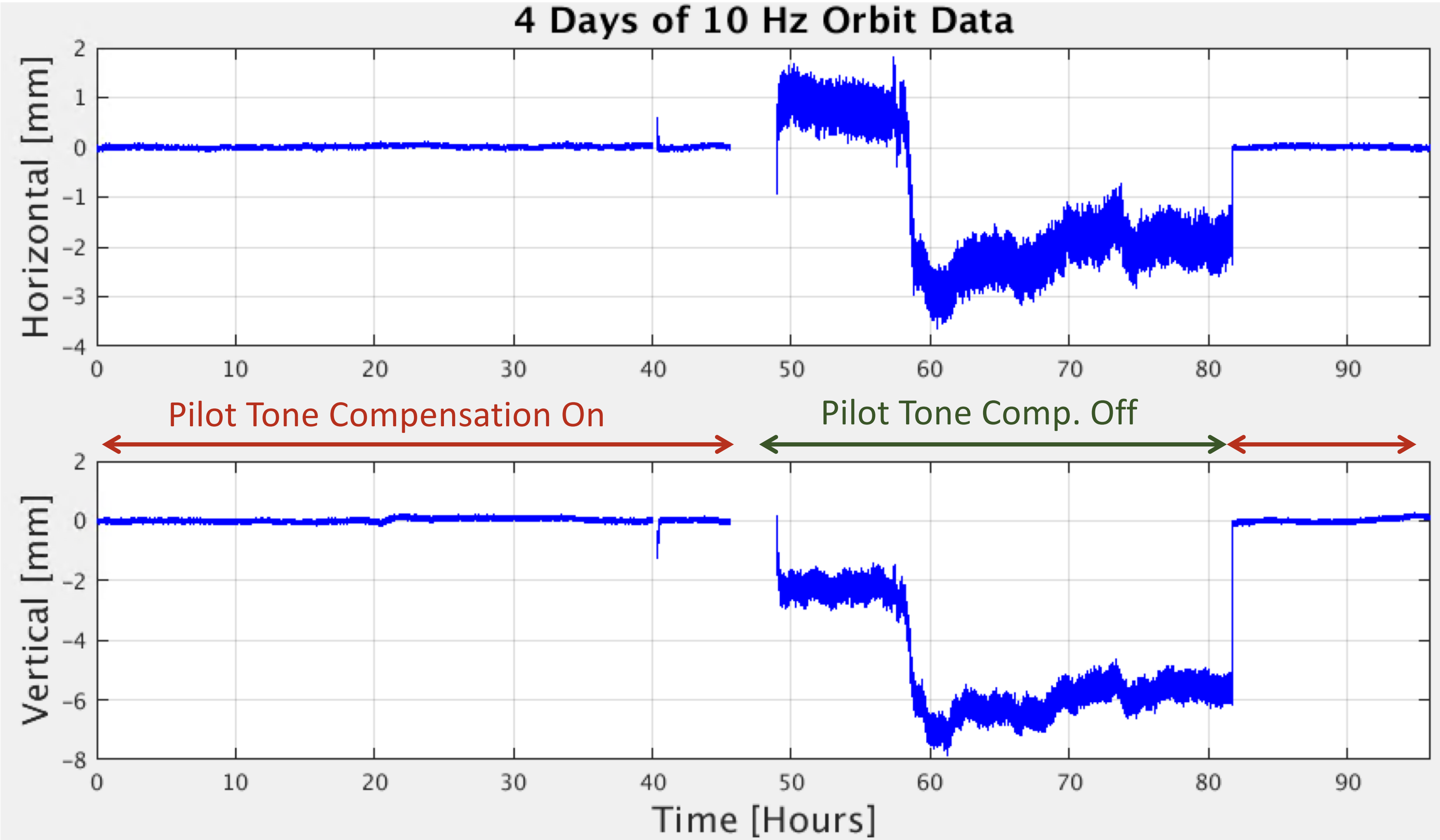
- BPM meets our 200 nm RMS noise floor goal from .4 Hz to 5 kHz w/ or w/o pilot tone correction.
- Pilot tone correction provides a benefit up to about 1 kHz. RMS noise from .4 Hz to 1 kHz is 75 nm.
- There is room for improving the pilot tone noise floor.

Beam & Noise Floor at 10 kHz



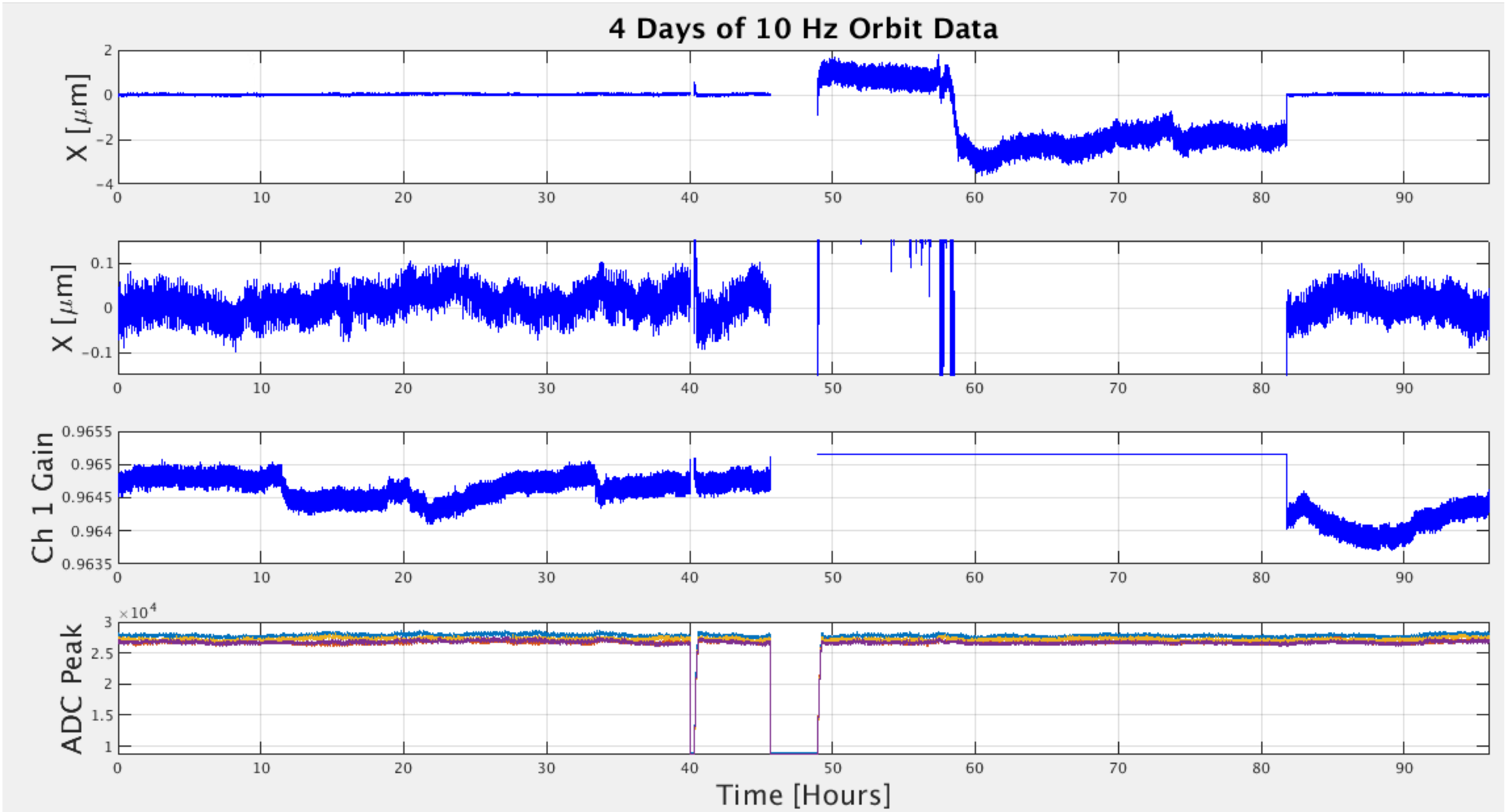
- The area between the lines shows the possible improvement factor if we upgrade our fast orbit feedback system.
- There isn't much beam motion above 1 kHz. It might be a challenge to measure beam motion above 5kHz. The solution is likely a combination of better ADCs (faster and/or higher resolution) and cleaner pilot tone generators.

4 Day Orbit Drift Measurement



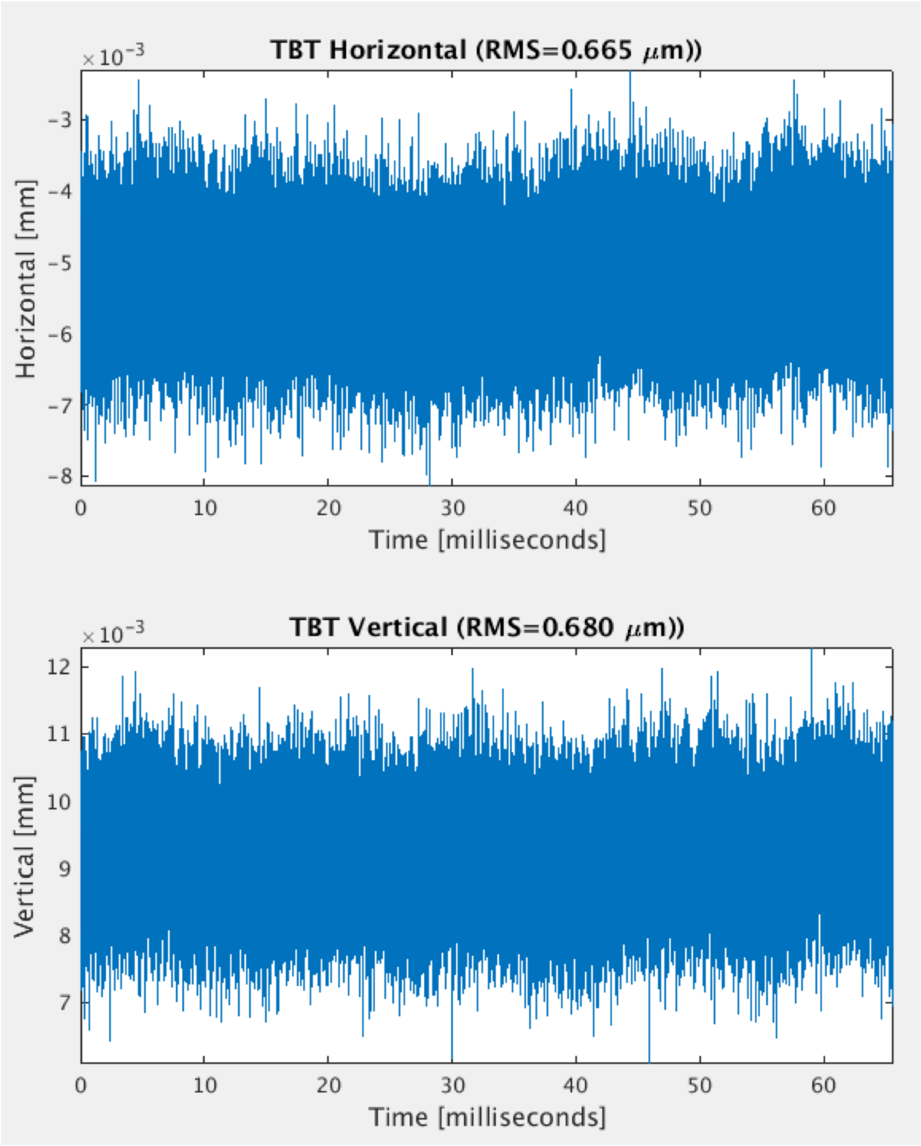
Orbit Drift Measurement (using a 4-way split button signal)

Drift measurement in more detail

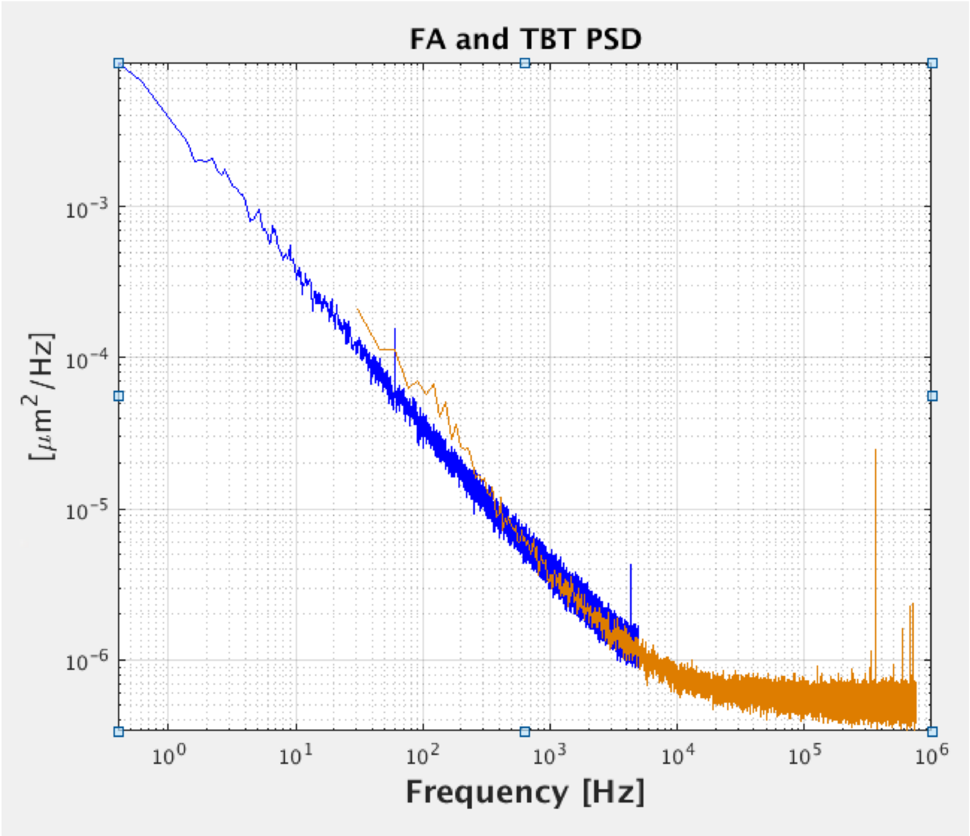


- Orbit Drift Measurement (using a 4-way split button signal)
- Maintained ±.2 μm RMS over 4 days with pilot tone compensation.

Multi-bunch Turn-By-Turn Orbit Measurement

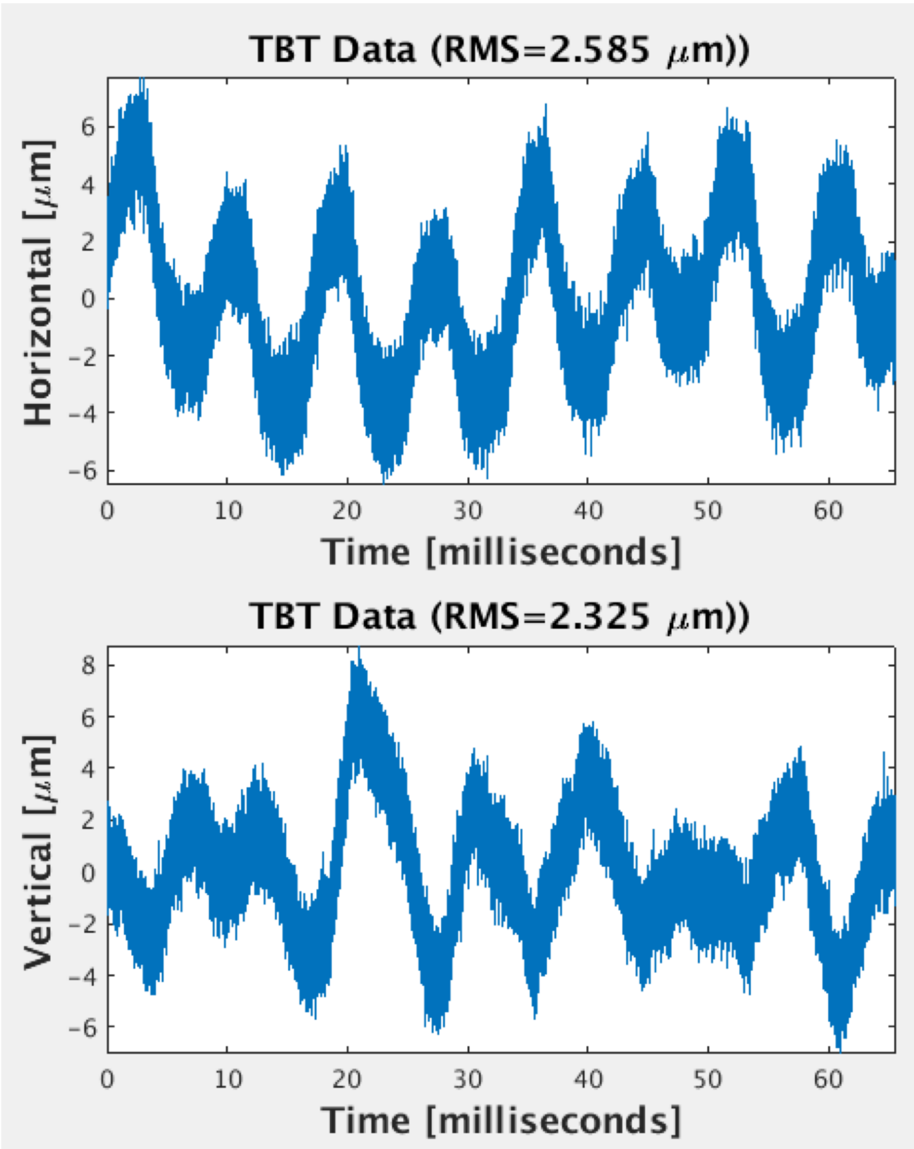


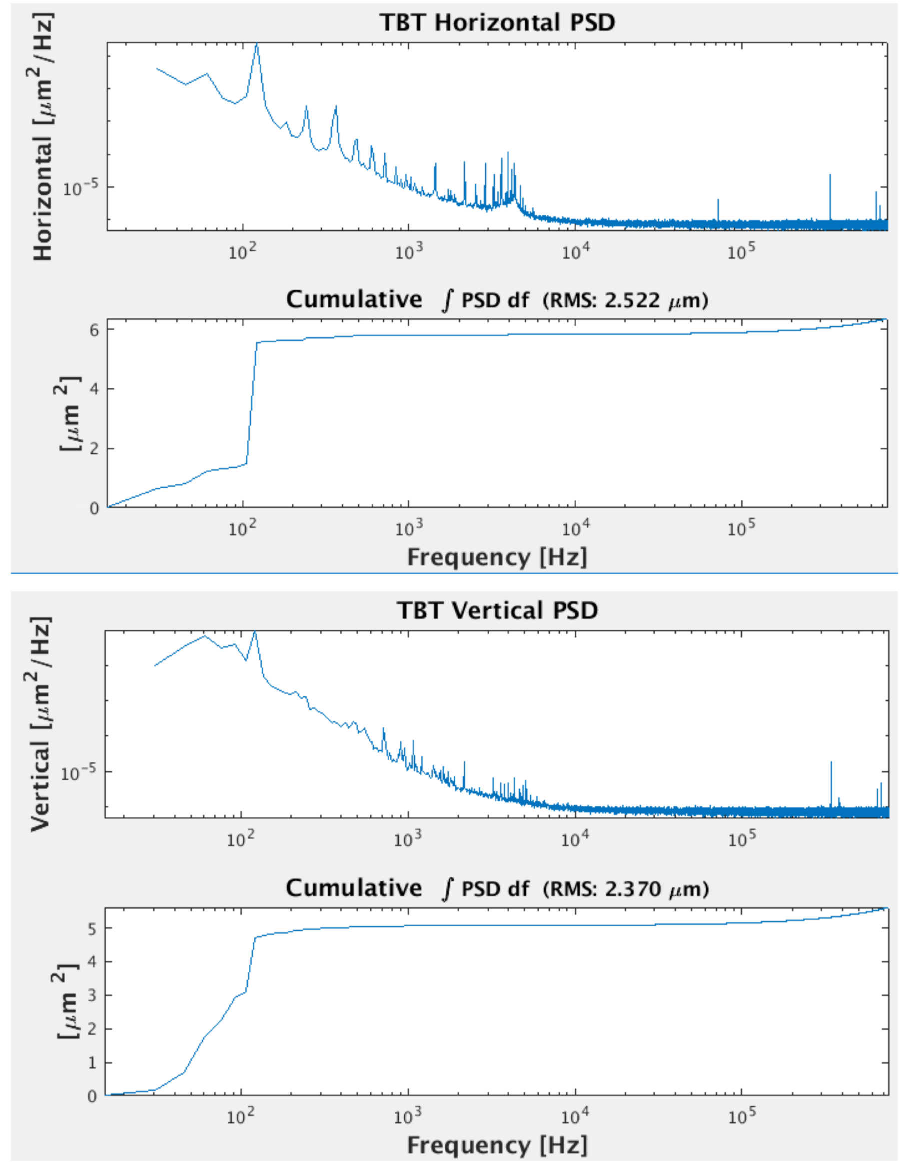
Noise measurement done at 500 mA using one button split 4-ways.



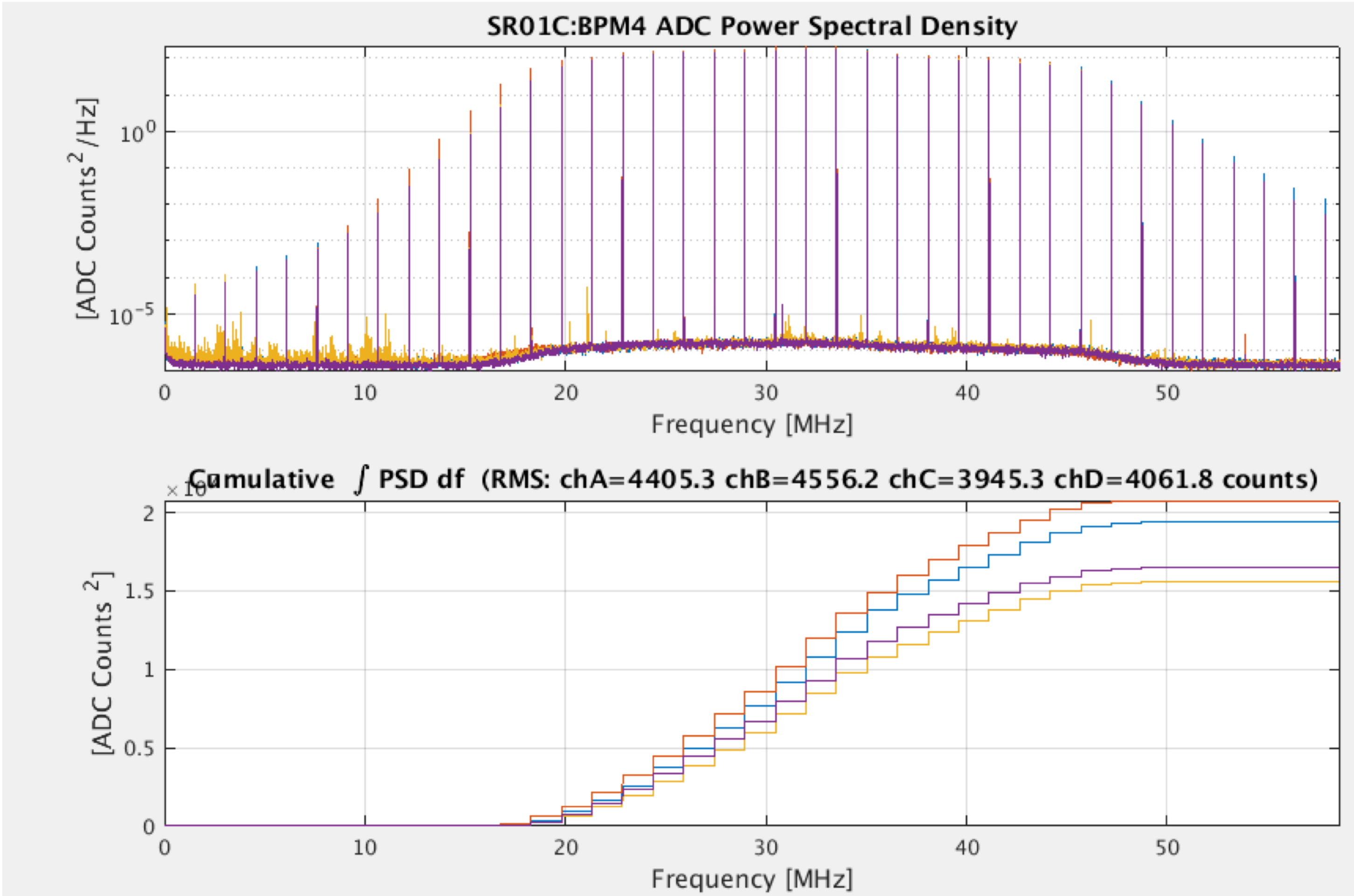
Multi-bunch Turn-By-Turn Orbit Measurement

Beam spectrum measurement





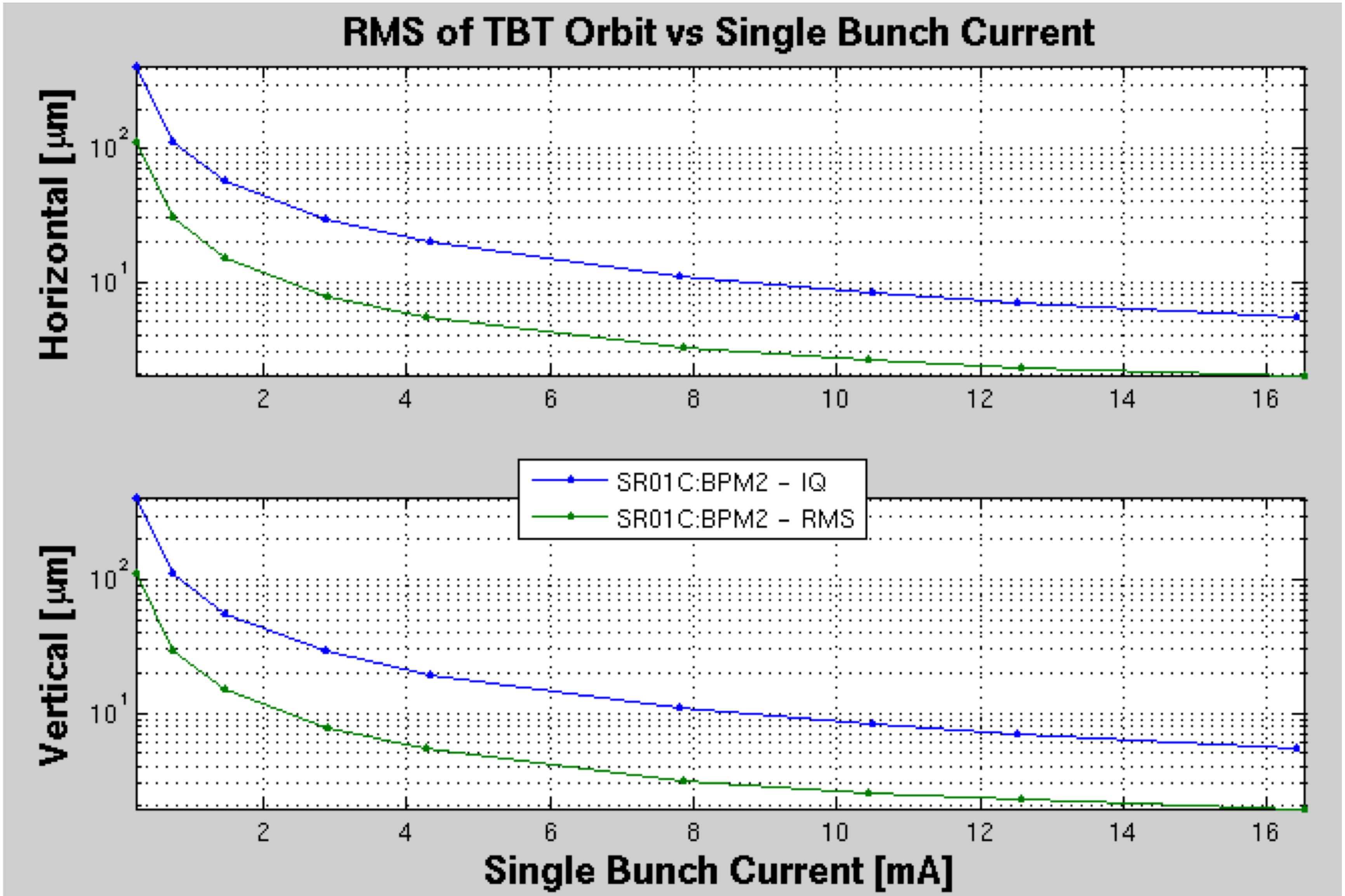
Single Bunch Turn-By-Turn Orbit Measurement



Two processing modes:

- IQ uses just the RF Rev Harmonic (the normal mode)
- RMS uses the whole spectrum

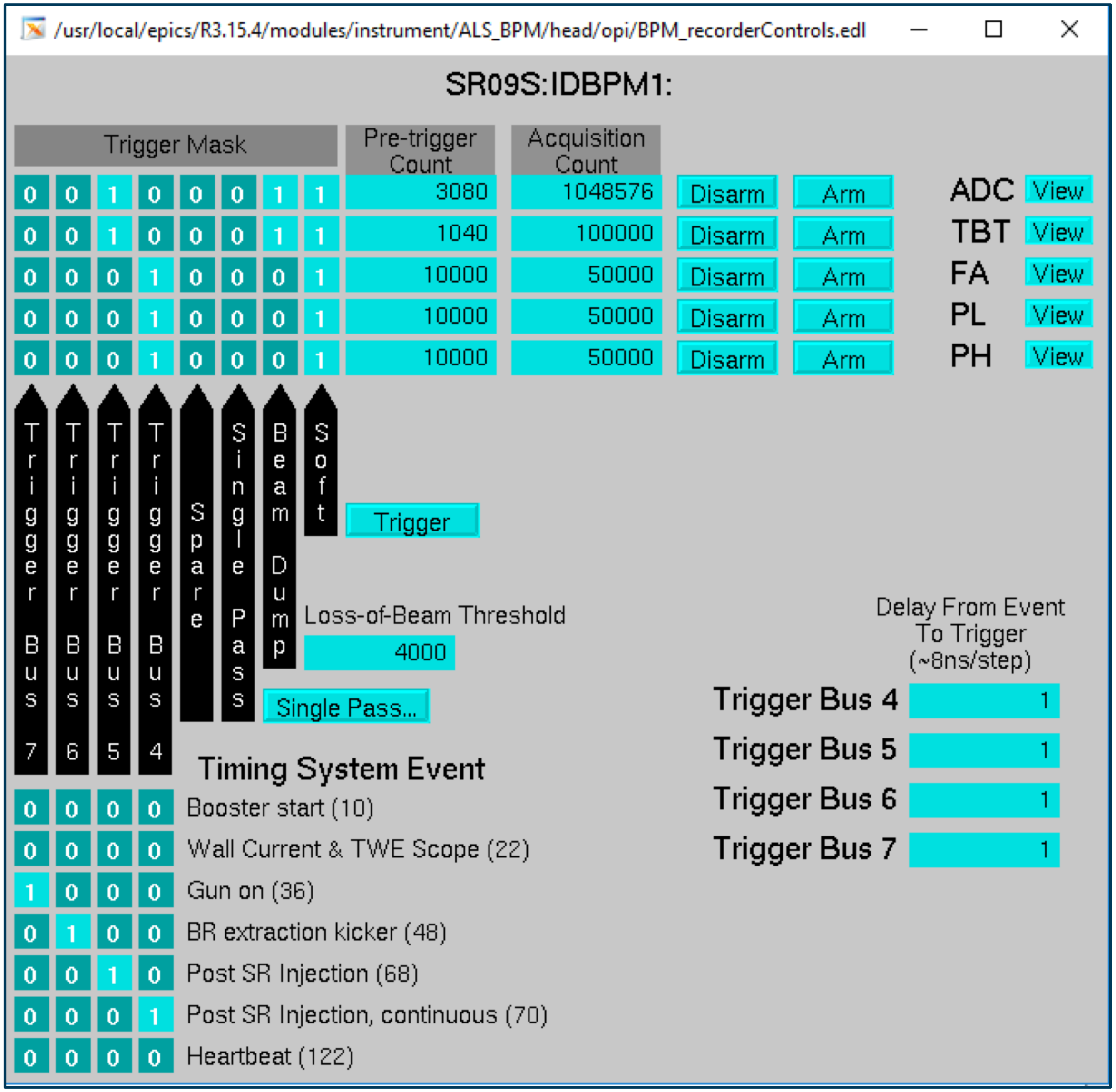
Turn-By-Turn, Single Bunch Orbit RMS



IQ uses just the RF Rev Harmonic, RMS uses the whole spectrum.

Data Recorder

- Data buffers for ADC, TBT, FA data streams with capacity up to 2^{24} samples (~16M)
- Trigger selection: any timing system (MRF) trigger, beam dump, single pass threshold, or software PV.



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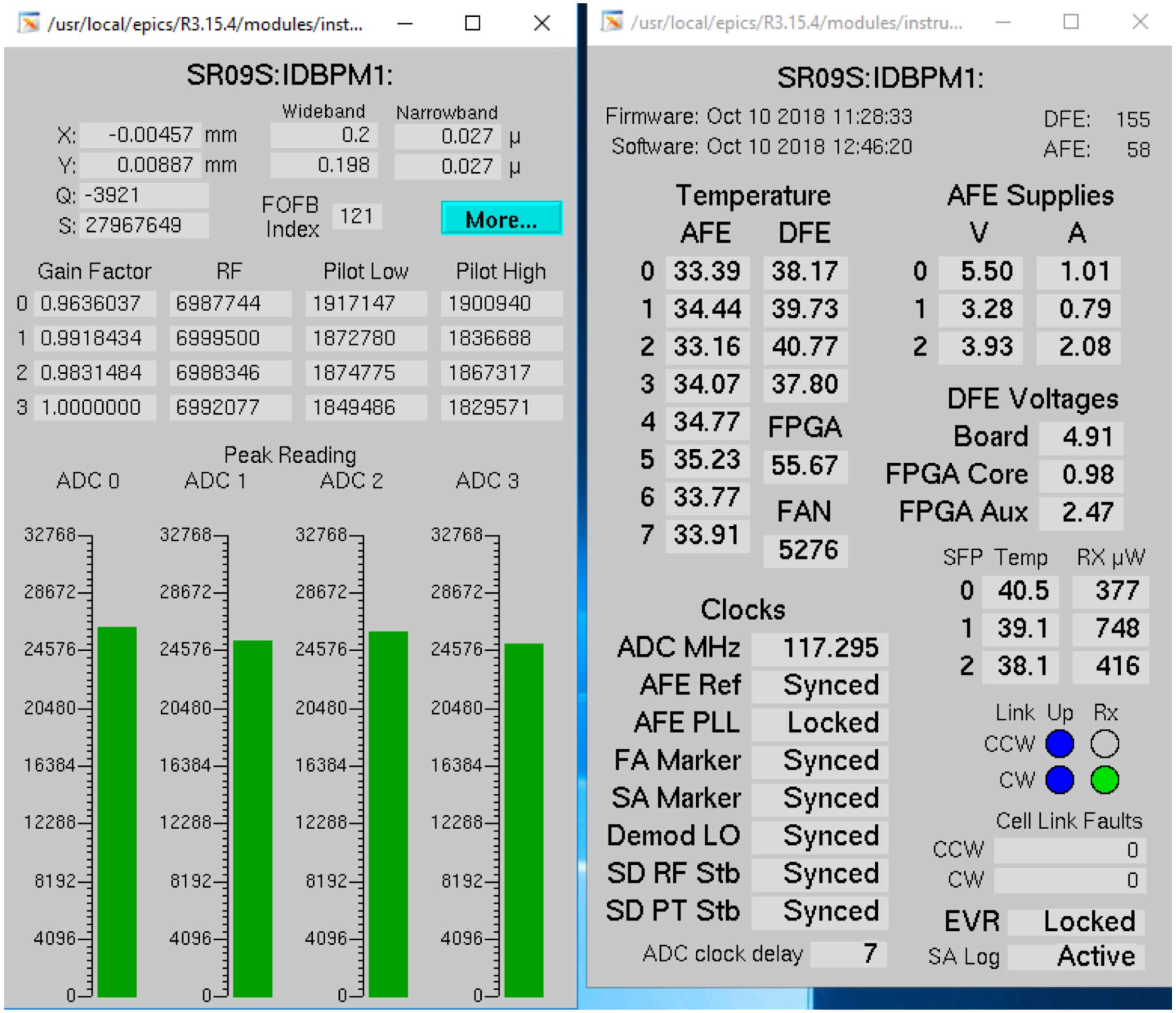
BPM Health Monitoring

- Health monitoring of temperature, voltages, clocks, etc.
- The pilot tone also provides an opportunity to run diagnostics checks on the BPM electronics during shutdown days. Presently, two pilot tones can be set on 5 different frequencies (including RF), and it could be expanded to include more frequencies.



BPM R&D

The wish list is the following.

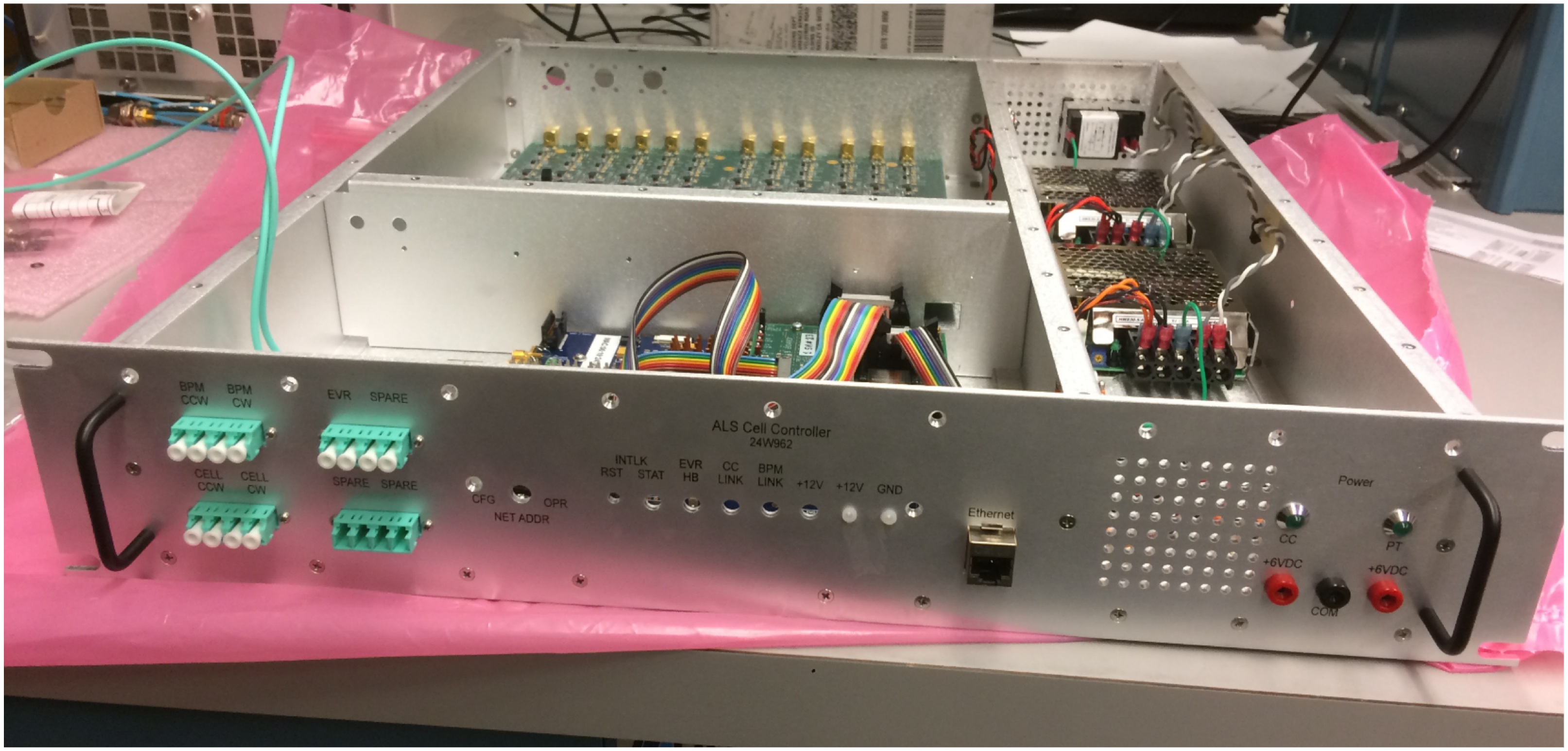
- Faster ADCs (presently ~125MHz)
  - 77 Samples / SR turn is a little low
- Component R&D
  - Bandpass filters
  - DAT, amplifiers, …
- Cleaner pilot tones
- 4 Channel ADCs
- Develop a pilot tones on RF compensation method

Hopefully ALS-U will provide an opportunity to address these issues.

Orbit Stability

Fast orbit feedback

Cell Controllers and FOFB



The ALS Cell Controller

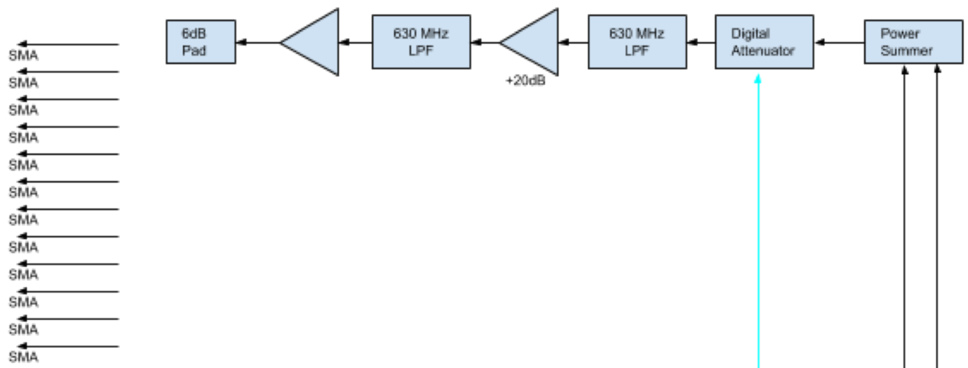
- Conceptually similar to NSLS2 FOFB System
- Different hardware, firmware, and software

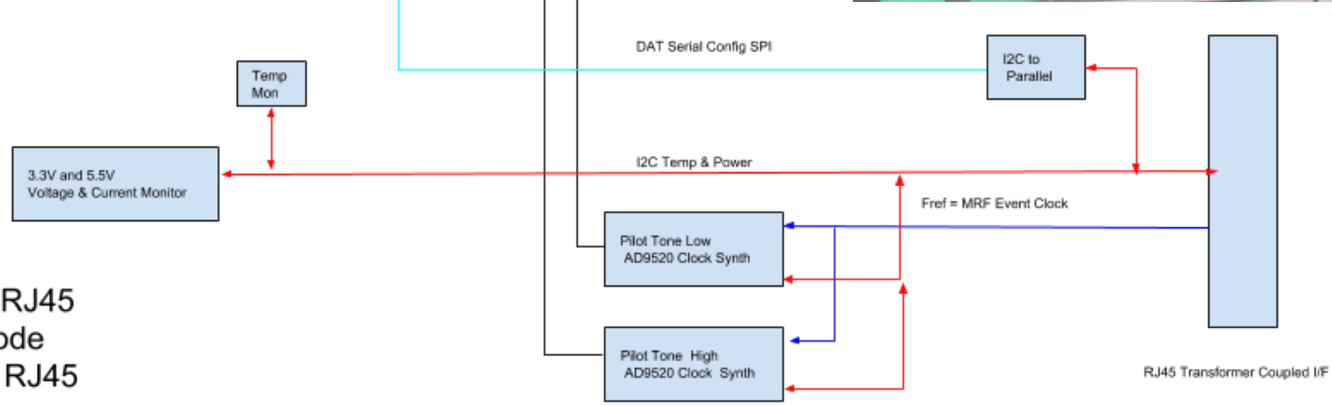
Multiple Functions

- FOFB – Collects BPM data at 10 kHz, computes the fast orbit feedback compensation, communicates to the fast power supplies
- Generates the pilot tones for the BPMs
- Fast orbit interlock (relay output)

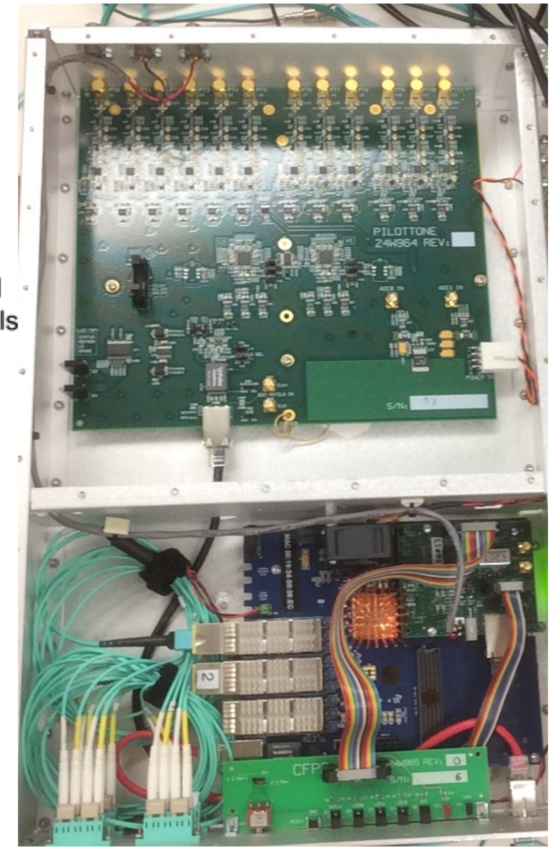
ALS Pilot Tone Generator

Pilot Tone Generator Diagram
Simplified





1 of 12 identical Analog Channels

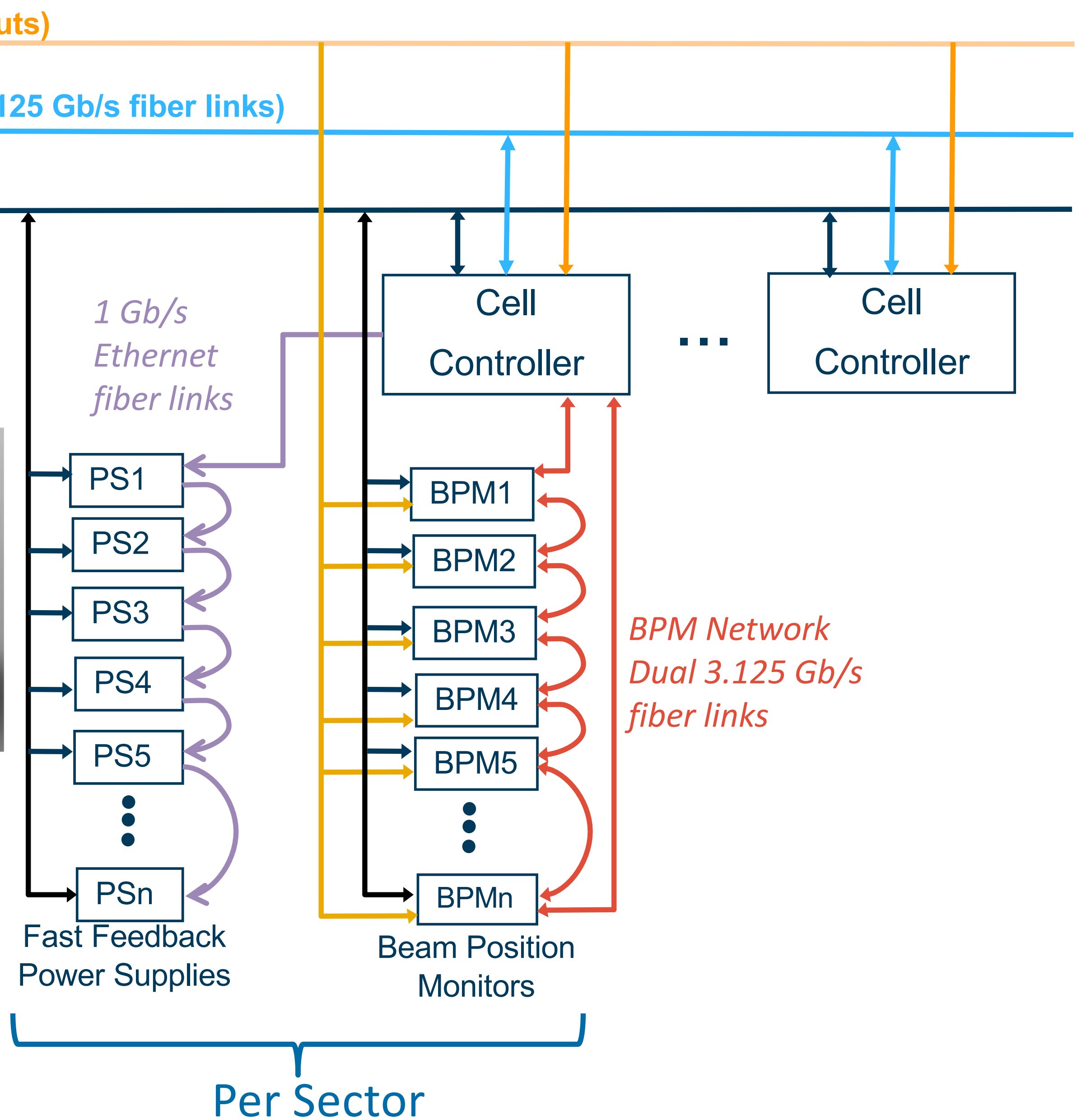


- Two Tone Generators
- Presently run at ±11/19 Rev Harmonic (~882 kHz)

Design Highlights

Transformer coupled I2C I/F using standard RJ45
Dual AD9520 Clock Synthesizers in VCO mode
125MHz Reference for Clock Generation on RJ45
Monitor Voltage/Current for 2 supplies
Backside of PCB is thermally connected to case
Each DAT is individually controlled

Fast orbit feedback architecture



Power Supply for FOFB
(Caen Fast-PS Series)

Fast Orbit Feedback System

- FPGA based, one cell controller per SR sector
- 3.125 Gb/s fiber links to local BPMs and to neighboring units
- 1 Gb/s ethernet fiber link to local fast corrector power supplies
- 10 kHz update rate
- < 20 µs latency from facility timing system 'fast acquisition' marker until new power supply setpoint transmission. Includes time to:
  - acquire position values from all local BPMs
  - acquire position values from all other fast feedback units
  - compute new power supply setpoints
  - transmit packet to local power supplies
- Provides orbits interlocking (relay output) at the 10 kHz rate with approximately 20 µs latency from the start of a BPM acquisition.

Orbit Feedback SystemTransition Plan

- Transitioning from Bergoz BPMs to our new BPM
  - Present state is,

    70 Bergoz, 52 New BPMs
  - In 2019 we hope to transition to,

    12 Bergoz, 112 New BPMs

- The present FOFB system uses both Bergoz and new BPMs at a 1 kHz data rate. *System commissioned by Christophe Steier, Simon Leemanns, Tom Scarvie, Eric Williams, … .*

- In 2019, we hope to transition to new Caen power supplies and increase the data rate to 10 kHz.

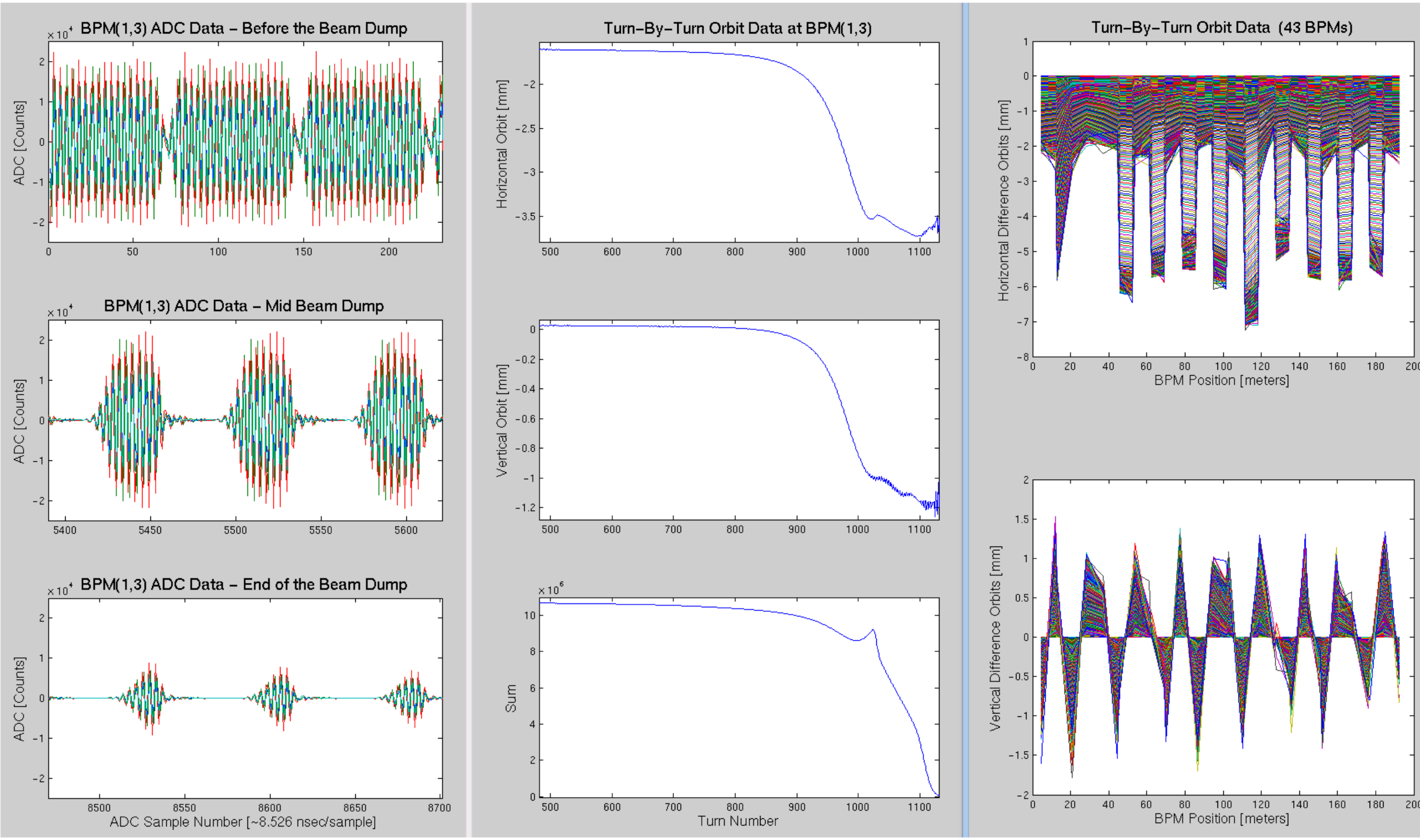
- We also have funding to replace the aluminum vacuum chambers at the fast correctors with higher bandwidth stainless steel chambers.

⇨ Aiming for a closed loop bandwidth between 500 to 1000 Hz

BPM Position Monitor

Fun Measurements

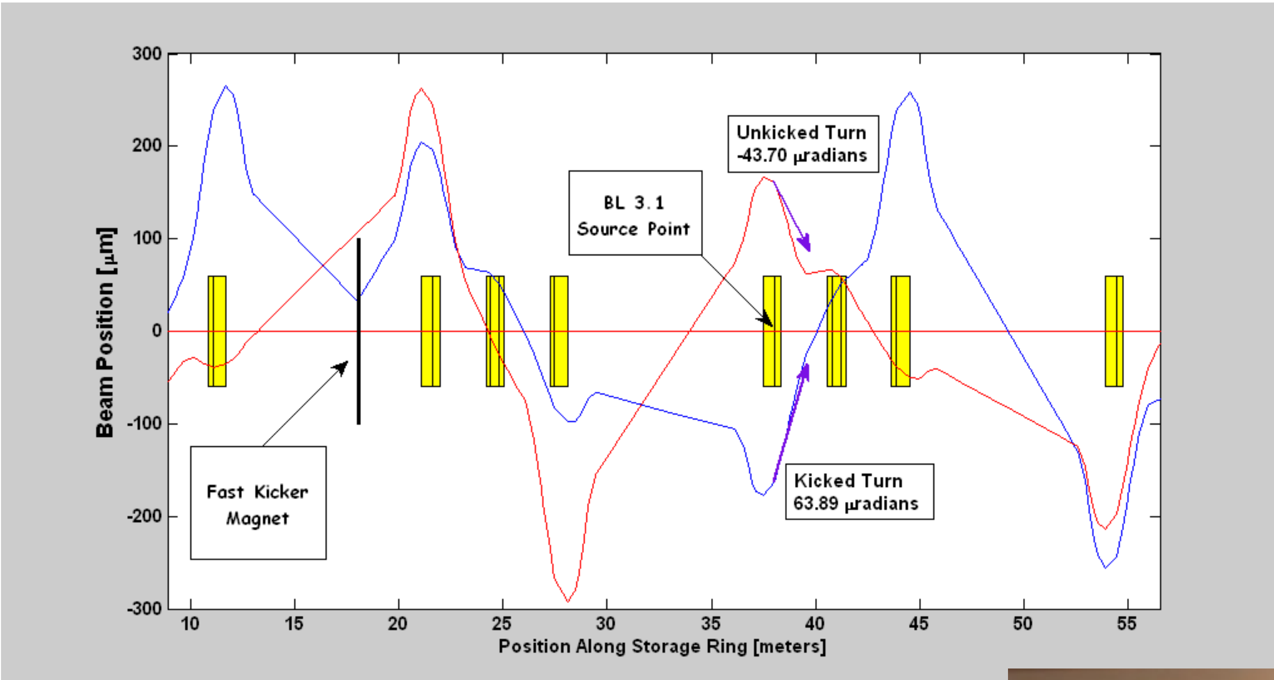
Beam Dump Monitoring at ALS



ADC buffers can also provide some limited fill pattern information.

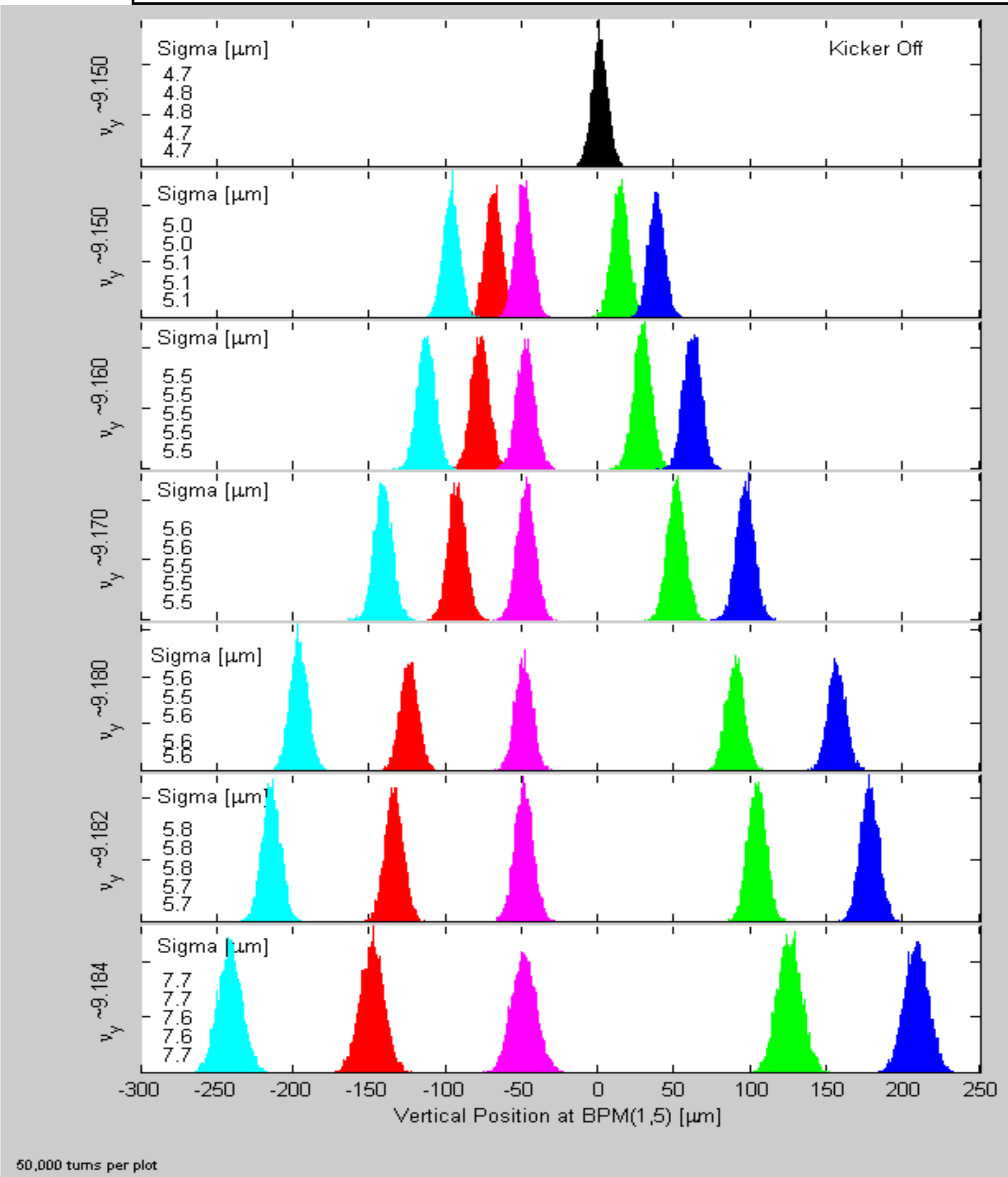
500 mA multi-bunch TBT is about .5 μm rms

Pseudo Single Bunch Kicker – Kicking Every Other Turn

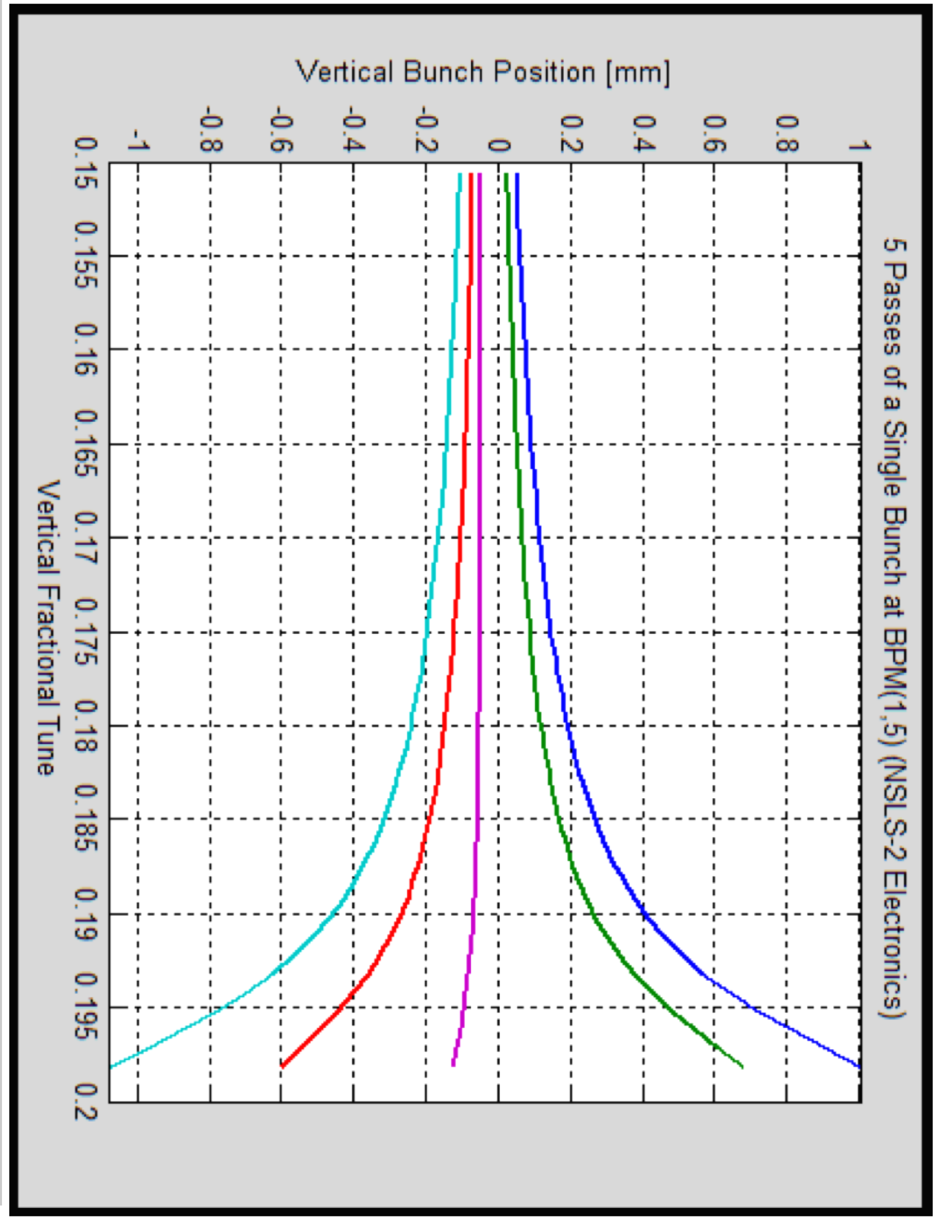


BL 3.1 Image for Single Bunch, 750 Volts on the kicker, 1.52/2 MHz

Pseudo Single Bunch Kicker – Kicking Every 5th Turn



BPM TBT Histogram at Different Vertical Tunes (NSLS2 BPM)



Model Orbits for Each of the 5 Turns Verses Vertical Tune

2-Bunch, Asymmetric Current

Fill pattern

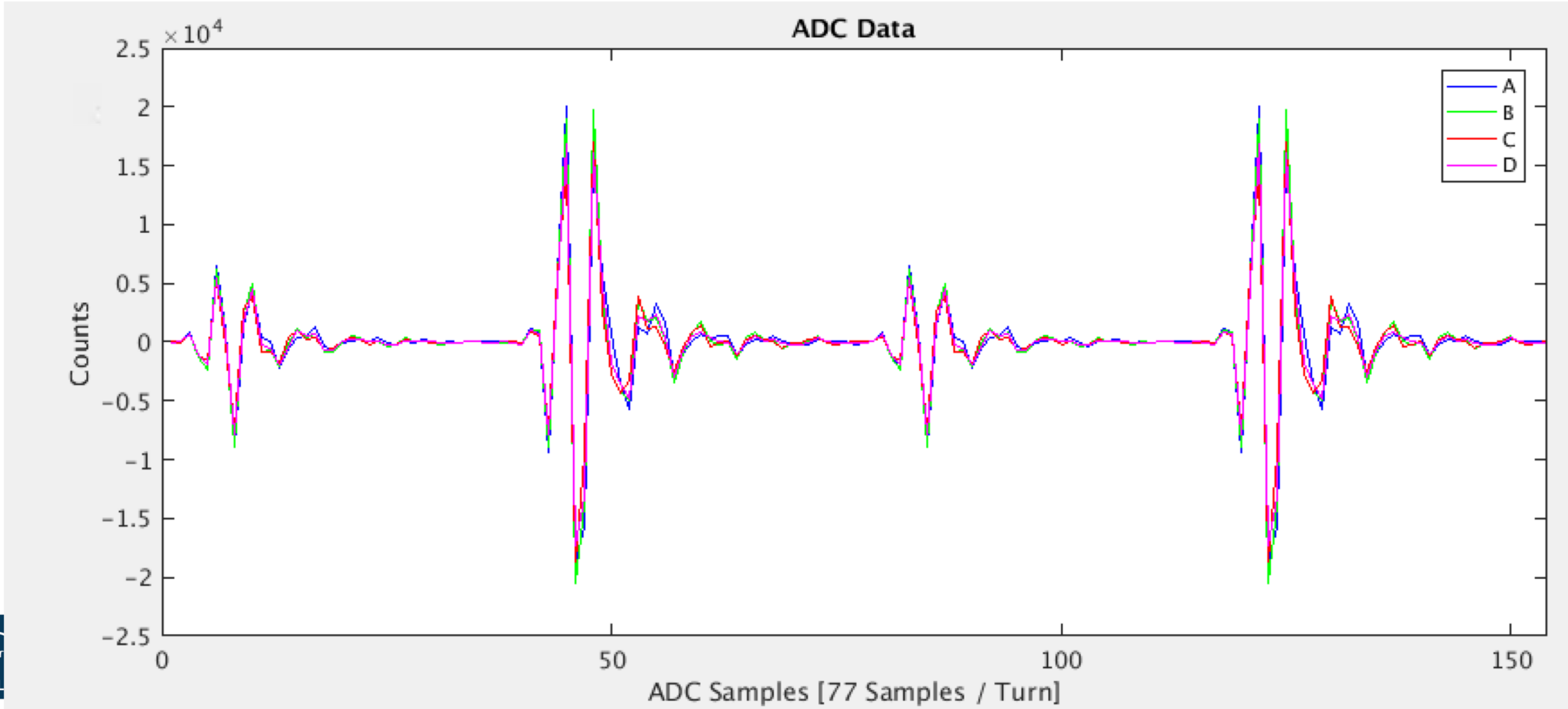
- About 1.2 mA each in bunches 144, 145, 146
- About 4.0 mA each in bunches 308, 309, 310

The fast injection magnets were used to kick the beam.

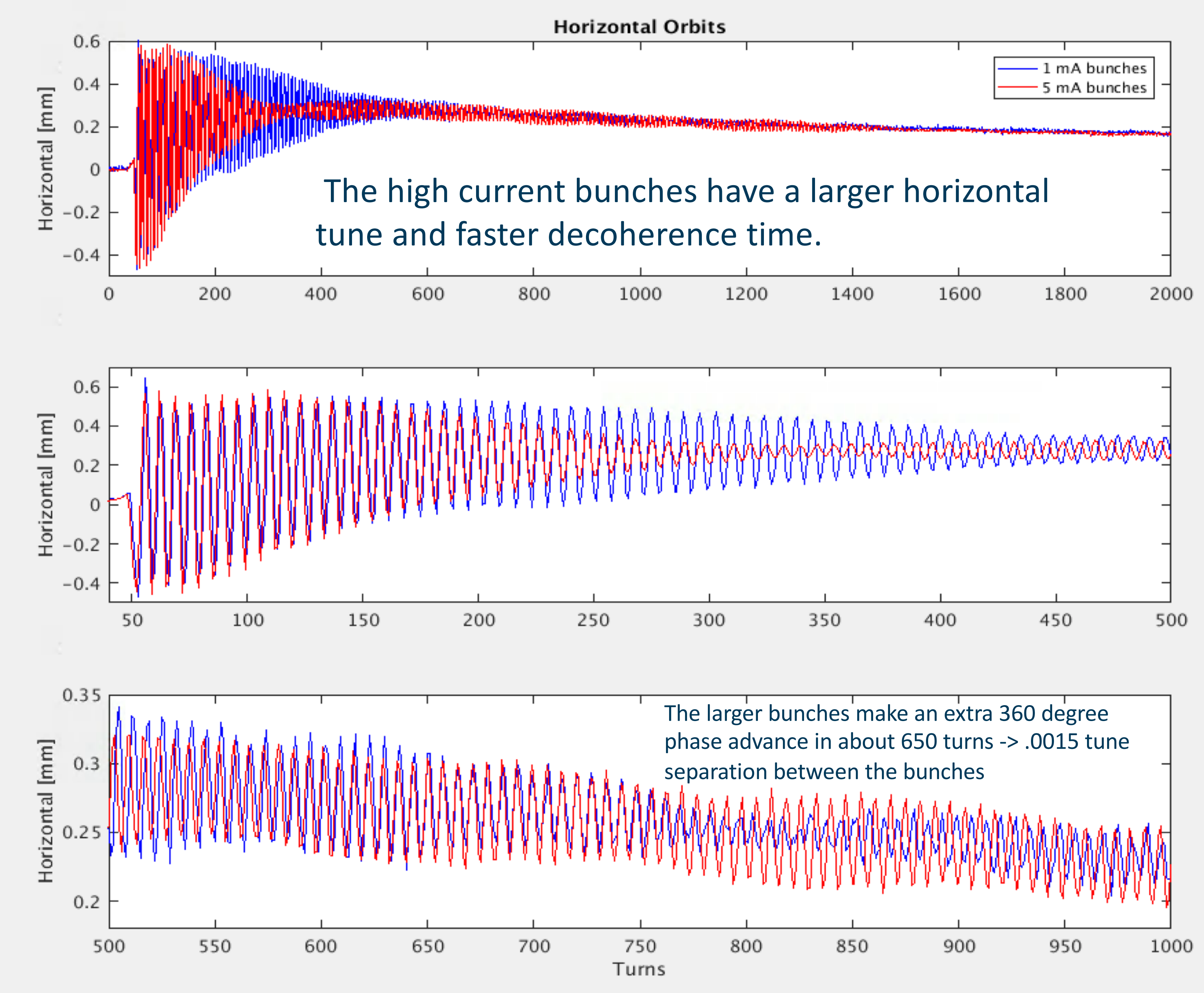
The orbits were computed using RMS ADC counts over half a turn (77 samples / turn):

Orbit1 from ADC samples 1:38 (the 1.2mA bunches)

Orbit2 from ADC samples 40:77 (the 4.0mA bunches)



2-Bunch, Asymmetric Current



Conclusion

- The pilot tone system is working well
  - For real-time compensation of BPM electronic errors
  - As a diagnostic tool for BPM health and performance

- We'd like to thank ALS management for supporting this effort!

- We'd like to thank the NSLS-II team for being bold and taking a new direction with BPM development. And providing us open access to their work.

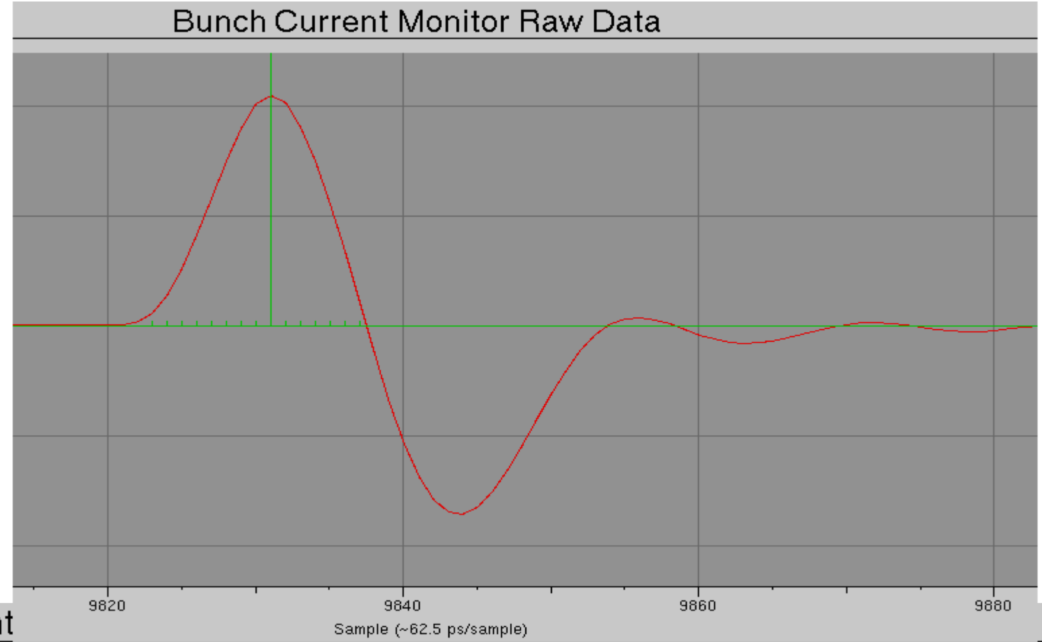
Extra Slides

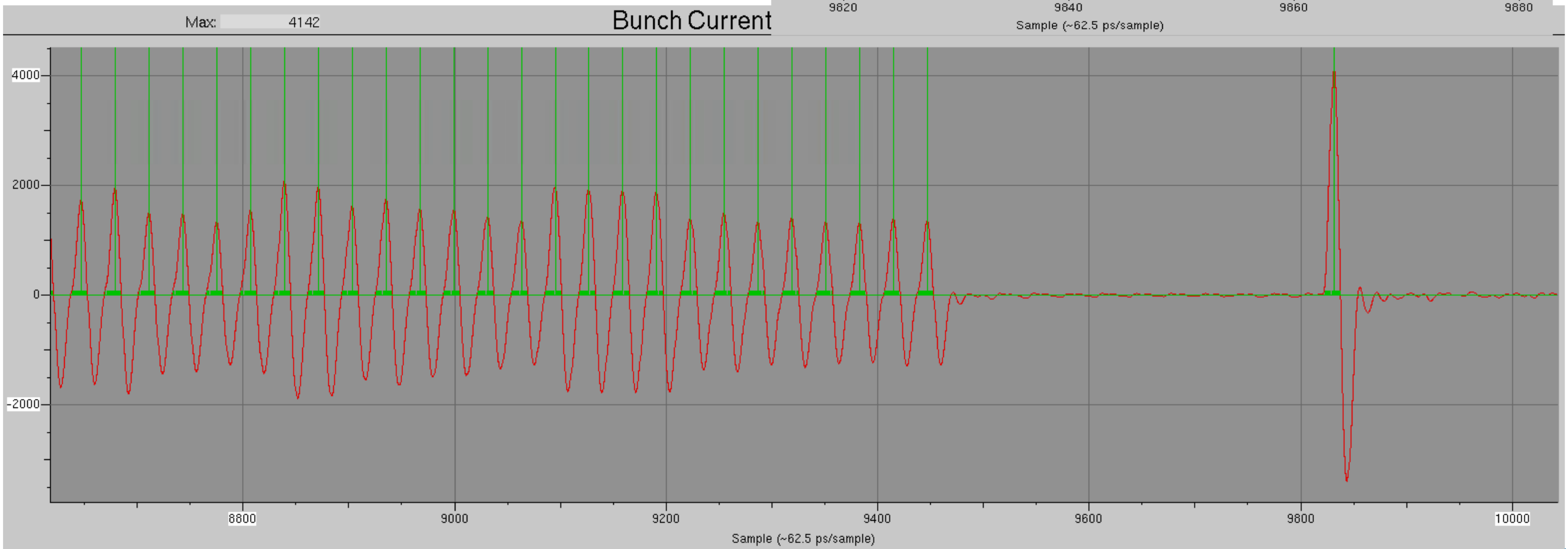
Bunch Current Monitor (BCM)

Bunch Current Monitor (BCM)

The bunch current and phase can be estimated from a BPM button signal by sampling a button signal at just off the RF frequency.

32 samples / 2 nsec





Bunch Current Monitor (BCM)