Towards sub-Micron Orbit Stability at NSLS-II

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for NSLS-II Accelerator Team

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Office of Science
U.S. DEPARTMENT OF ENERGY

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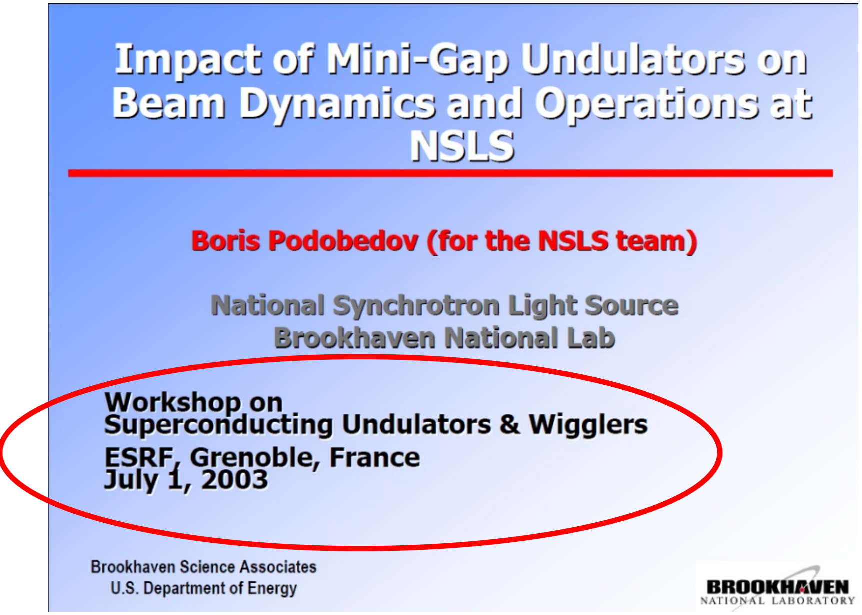
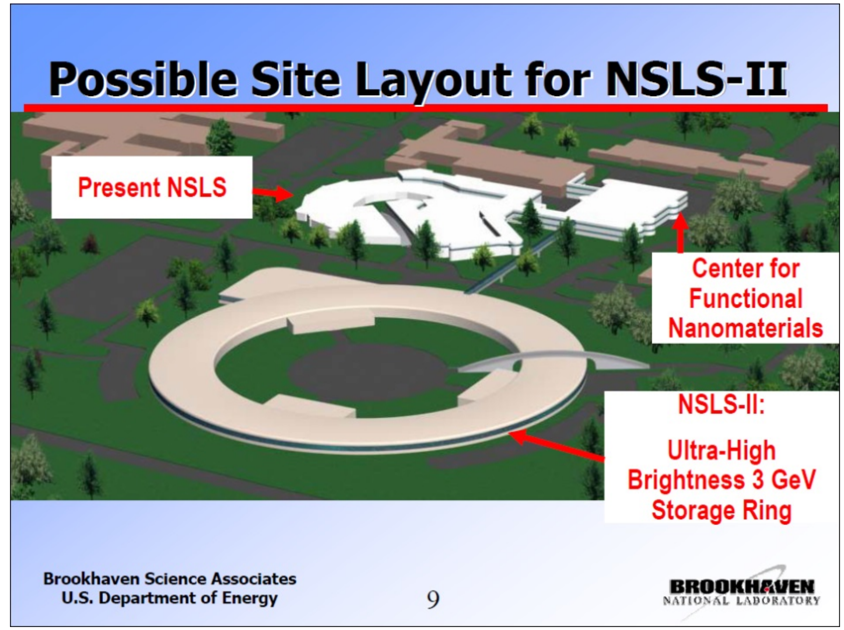
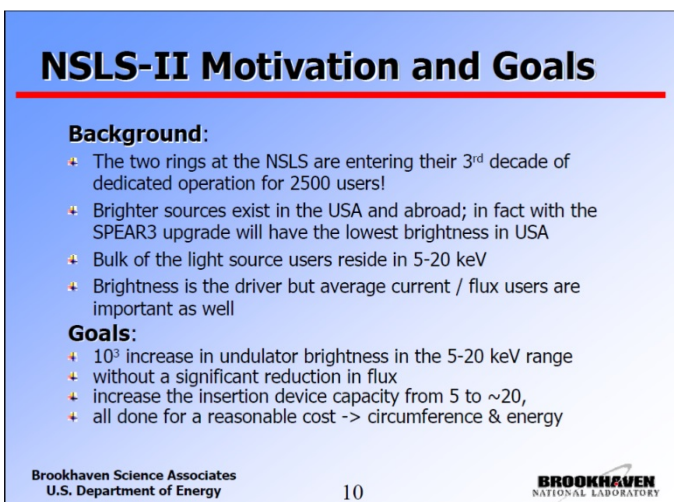
12 Years Ago Here

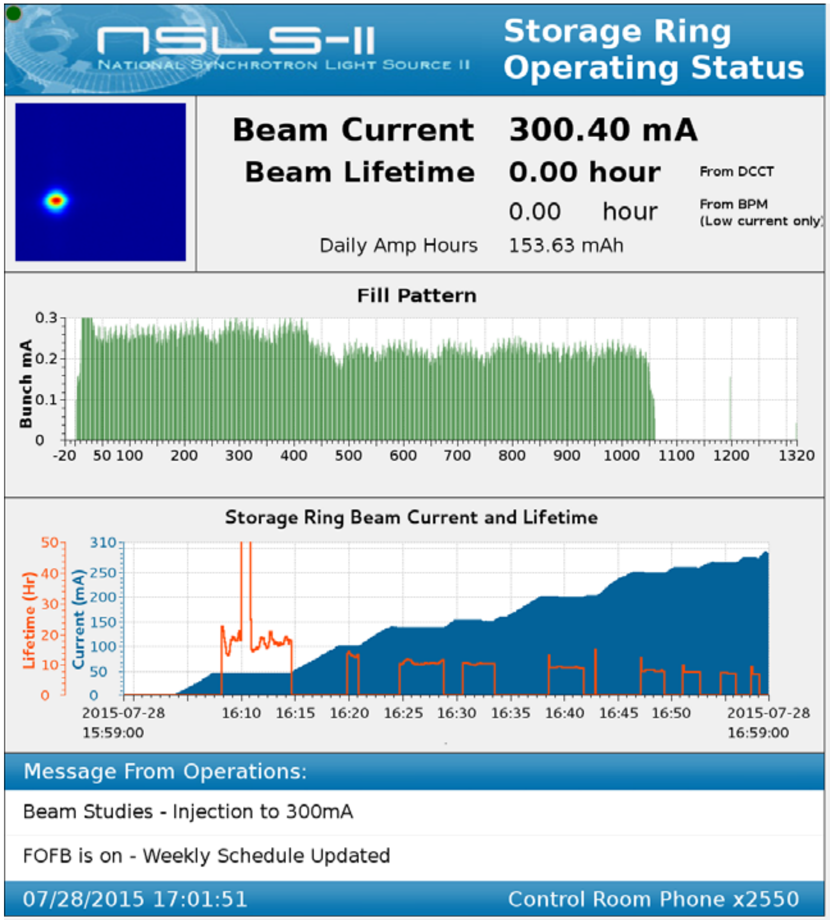


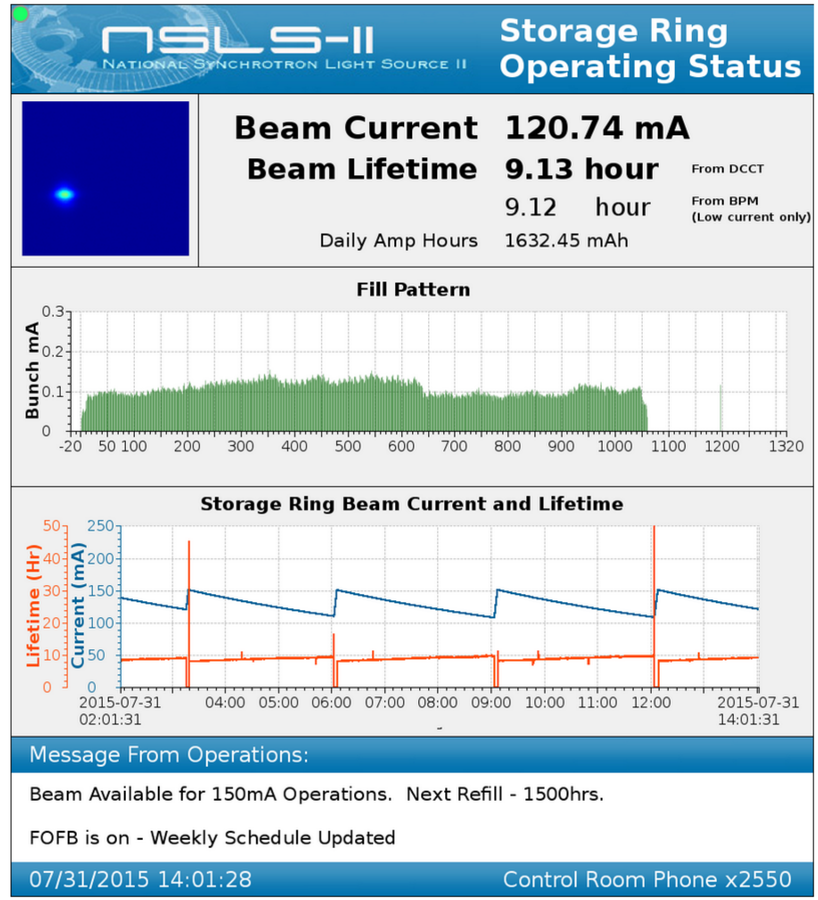




The first talk that mentions NSLS-II

Recent NSLS-II Storage Ring Performance

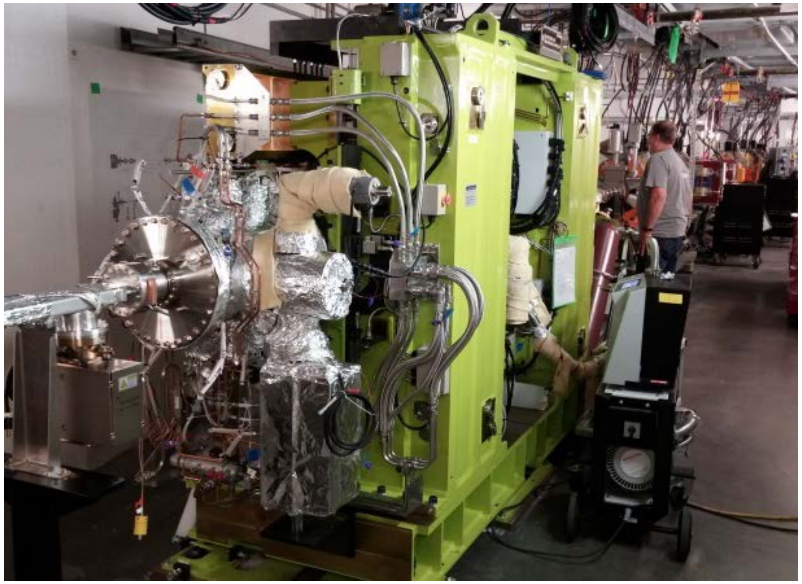




300 mA!

Routine Ops at 150 mA

Insertion Devices: ~15 Installed and More on the Way

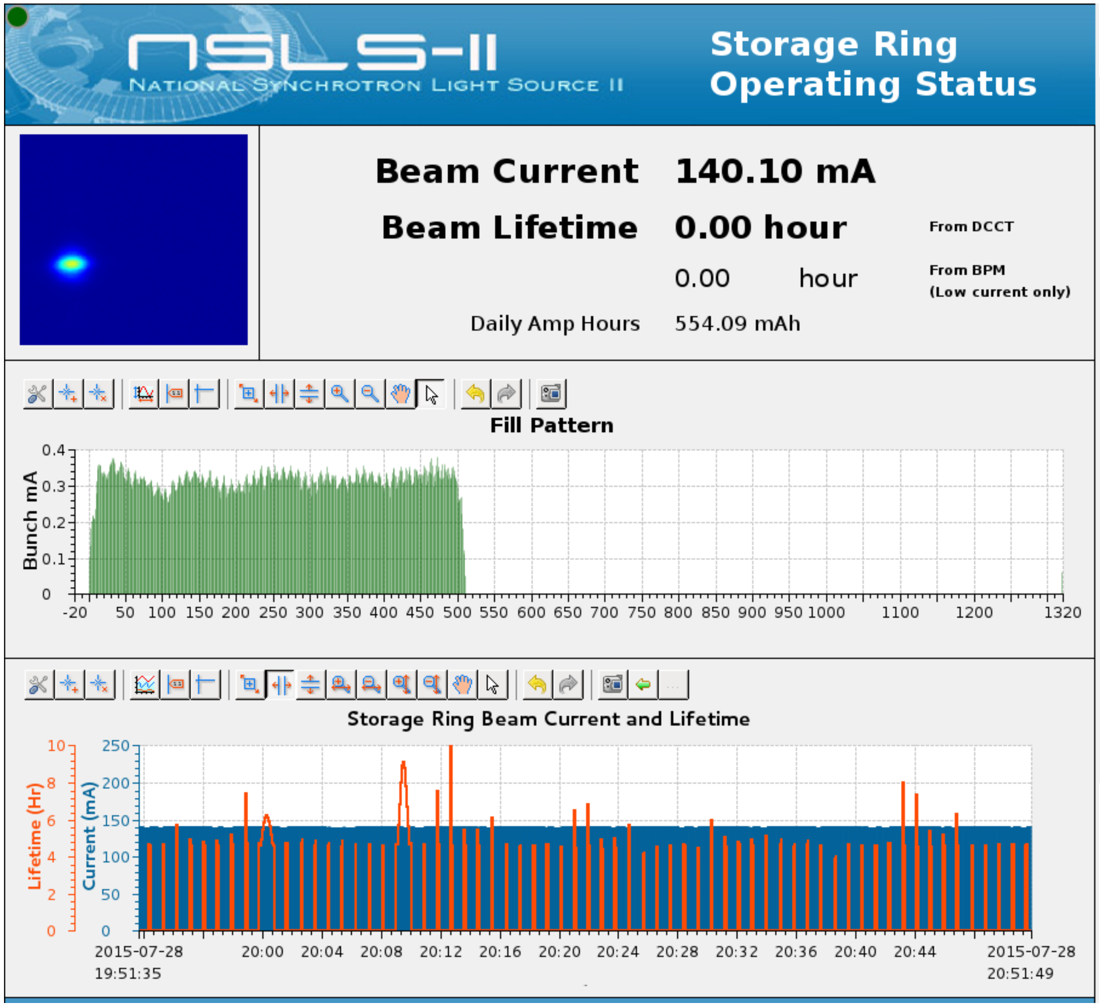


Installation of In-Vacuum Undulator

for ISR beamline, cell 4, this August

As of summer 2015:
7 IVUs
2 EPUs
3x2 DW

Next Step: Top-off Operations



Preparation for Top-Off operation continues at a good pace.

- ✓ 20% bunch-to-bunch variation has been achieved (ignoring the leading and trailing bunches)
- ✓ 0.5% variation in ring current has also been achieved.

The Top-Off Safety System fabrication and installation is continues on schedule.

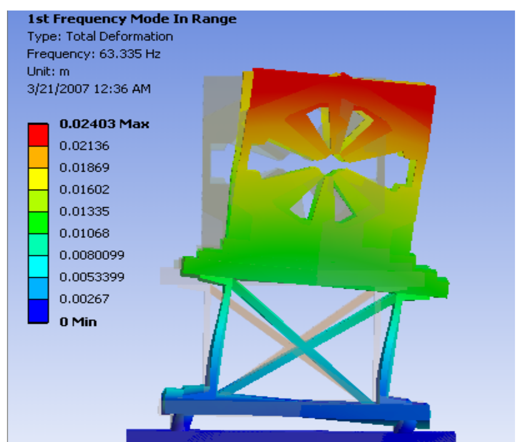
Ray Flliler

Results from Top-Off Injection Studies on July 28th

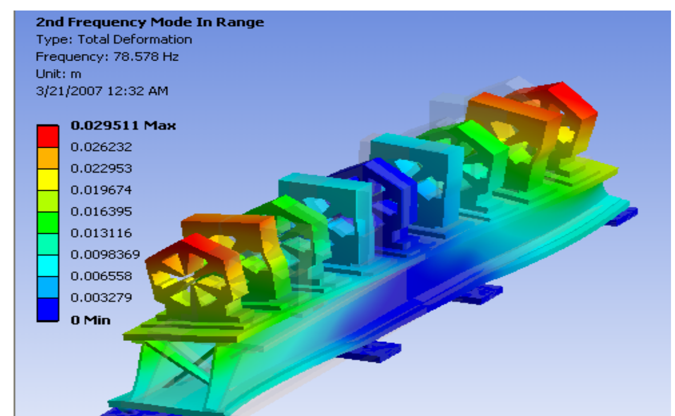
High Stability Design Approach

- Most NSLS-II systems were designed and built with high stability in mind
- Stringent specs on most electrical and mechanical systems (PS regulation, vibration, thermal regulation, girder design, etc.)
- Many studies verifying the design, i.e. vibration analysis
- High resolution and stable BPMs designed and built
- Fast orbit feedback system (FOFB).
- …

Sushil Sharma



(a)



(b)

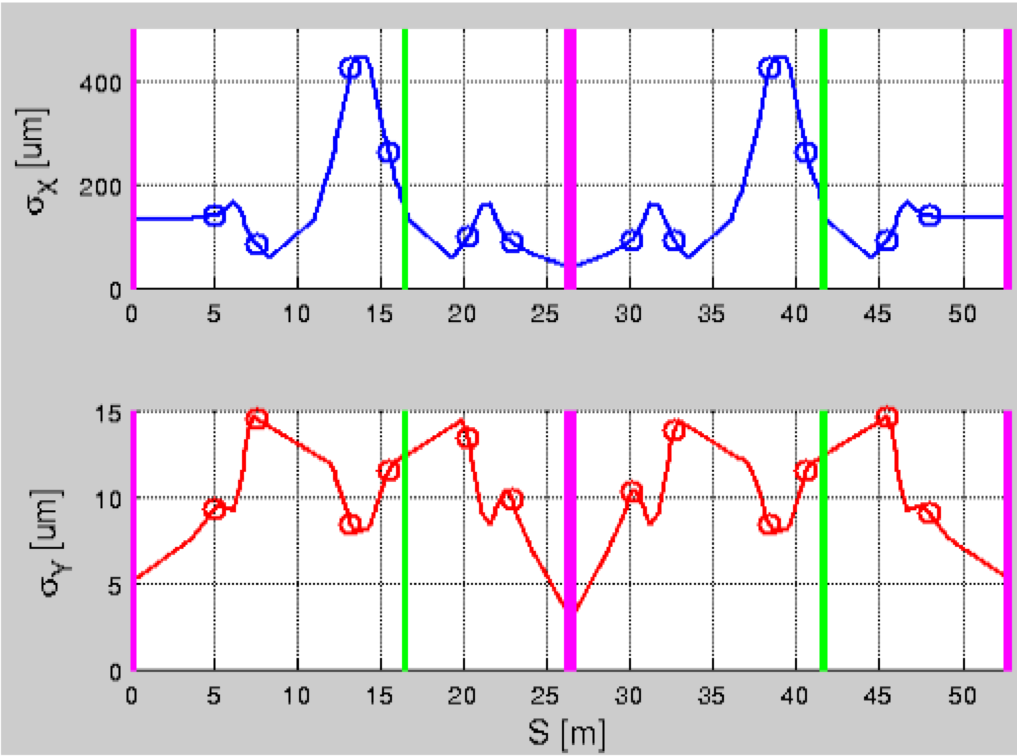
Natural modes of vibration for the girder-magnets assembly

These efforts have largely payed off

NSLS-II Storage Ring Design Parameters

Energy	3.0 GeV	RF Frequency	499.68 MHz
Circumference	792 m	Harmonic Number	1320
Number of Cells	30 DBA	RF voltage	4.8 MV
Number of Super-periods	15	RF Bucket Height	4.1%
Length ID Straights	6.6 & 9.3m	RMS Bunch Length	11.5ps
Emittance with DW (h/v)	0.9 nm/ 8 pm	Average Current	500 mA
Momentum Compaction	.00037	Current per Bunch	~0.5 mA
Dipole Bend Radius	25m	Touschek Lifetime	>3hrs
Energy Loss per Turn (with DW)	0.675MeV	Top-Off Injection Freq	1/min
Energy Spread (with DW)	0.094%	Charge from one injection	7.3nC
		Stability requirement	<10% beam size

RMS Beam Sizes and Orbit Stability Specs



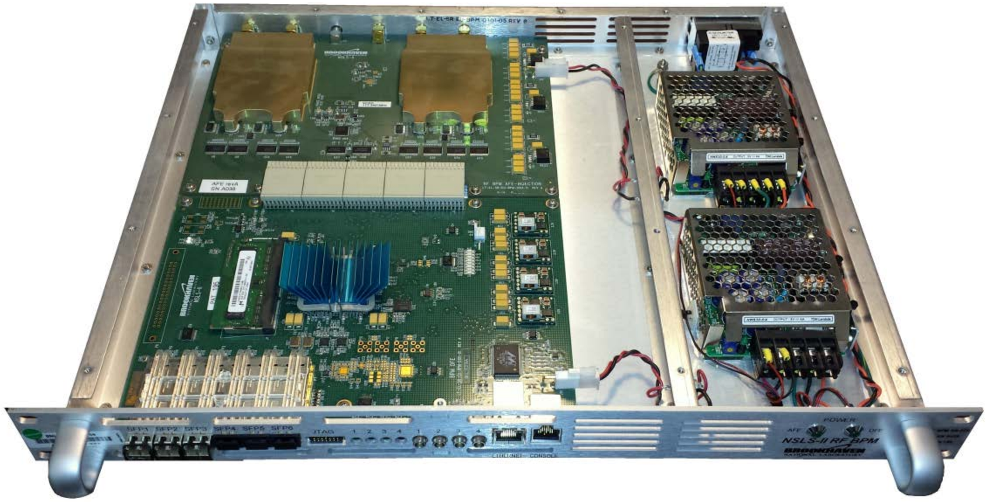
Lines: RMS sizes
Ver. bars: user source points
Circles: RF BPMs (total 180)

Not shown: ID RF BPMs (2-3 per ID straight)
XBPMs (photon BPMs, 4 so far)

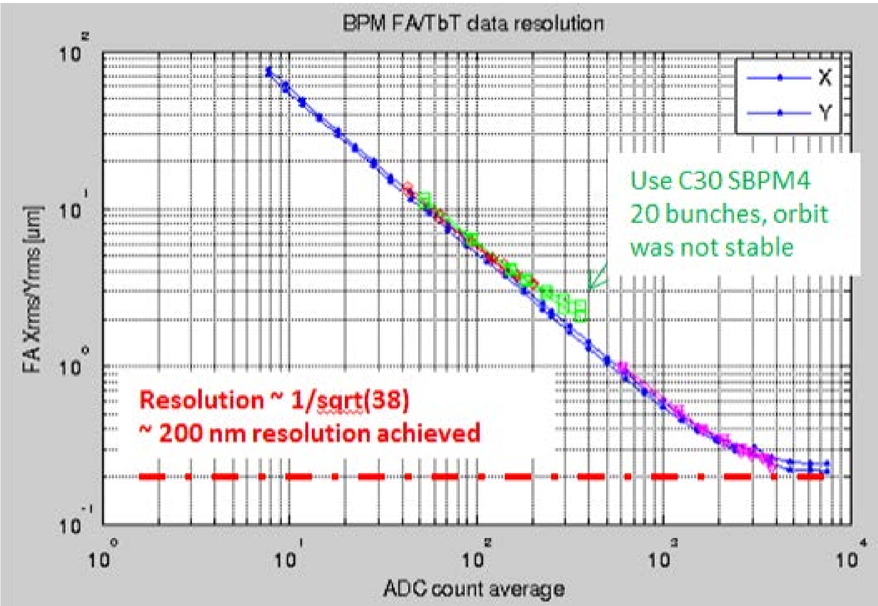
- Calculated beam sizes for ε_x=0.9 nm, ε_y = 8 pm, $\delta E/E$=0.09%
- Smallest beam size in the center of low-β straight σ_x=41 μm, σ_y = 3.1 μm
- Our goal to have orbit stable to 10% of these values, i.e. <0.3 μm rms
- Most stringent angular stability is at the high-β straight, 0.1σ_y'=0.15 μrad

NSLS-II BPMs

Data Type	Mode	Max Length
ADC Data	On-demand	256Mbytes or 32M samples per channel simultaneously
Single-Pass	Streaming	800hr circular buffer (1Hz Injection)
TbT	On-demand	256Mbytes or 5 M samples Va,Vb,Vc,Vd, X,Y,SUM, Q, pt_va,pt_vb,pt_vc,pt_vd
FOFB 10KHz	Streaming via SDI Link & on demand	Streaming - X,Y,SUM; For on demand: 256 Mbytes or 5 Msamples. Va,Vb,Vc,Vd, X,Y, SUM, Q, pt_va,pt_vb,pt_vc,pt_vd
Slow Acquisition 10Hz	Streaming and On-demand	80hr circular buffer Va,Vb,Vc,Vd, X,Y,SUM, Q, pt_va,pt_vb,pt_vc,pt_vd
System Health	Streaming & on-demand	80hr circular buffer AFE temp, DFE temp, FPGA Die temp, PLL lock status, SDI Link status



J. Mead, W. Cheng

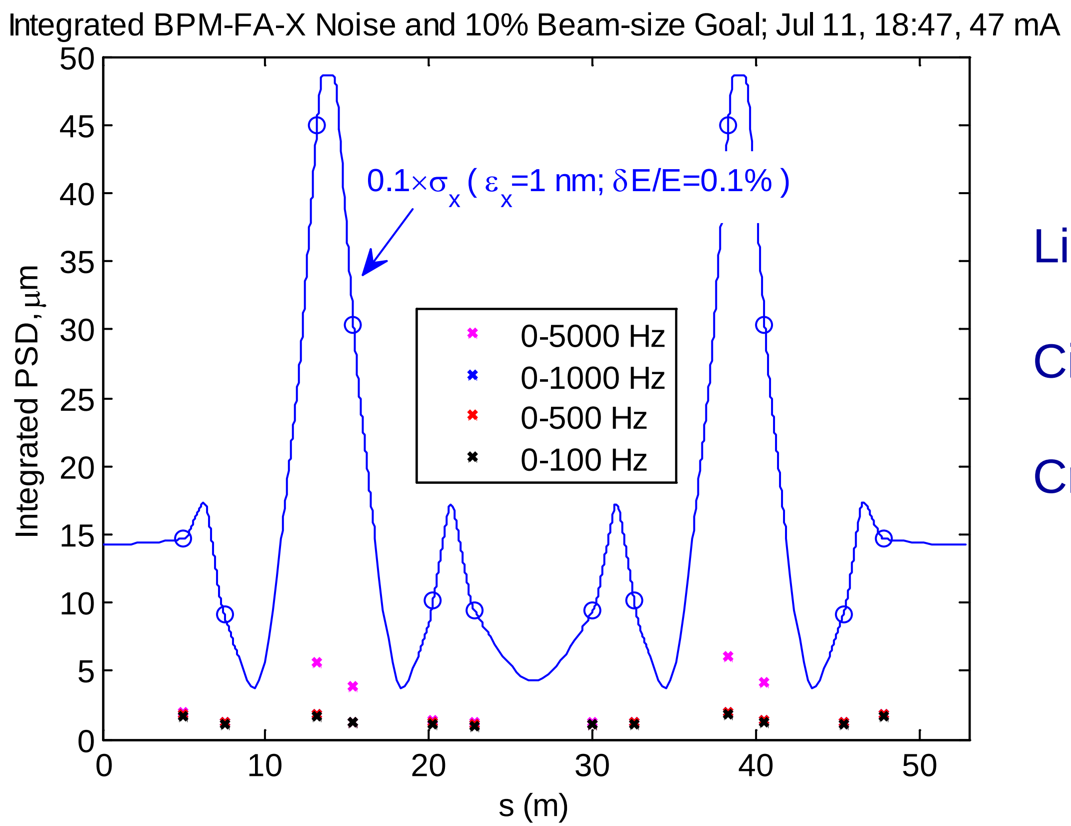


- Original NSLS-II development (by Kurt Vetter et al.)
- Resolution specs of 1 μm turn-by-turn (TbT) and 200 nm in 10 kHz (FA) mode were verified with beam
- FA is used for fast orbit feedback

What We Understand about Orbit Noise

Horizontal Orbit Stability without Feedback

- July 2014, 1 sec of 10 kHz (FA) data



Line: 10% beam sizes

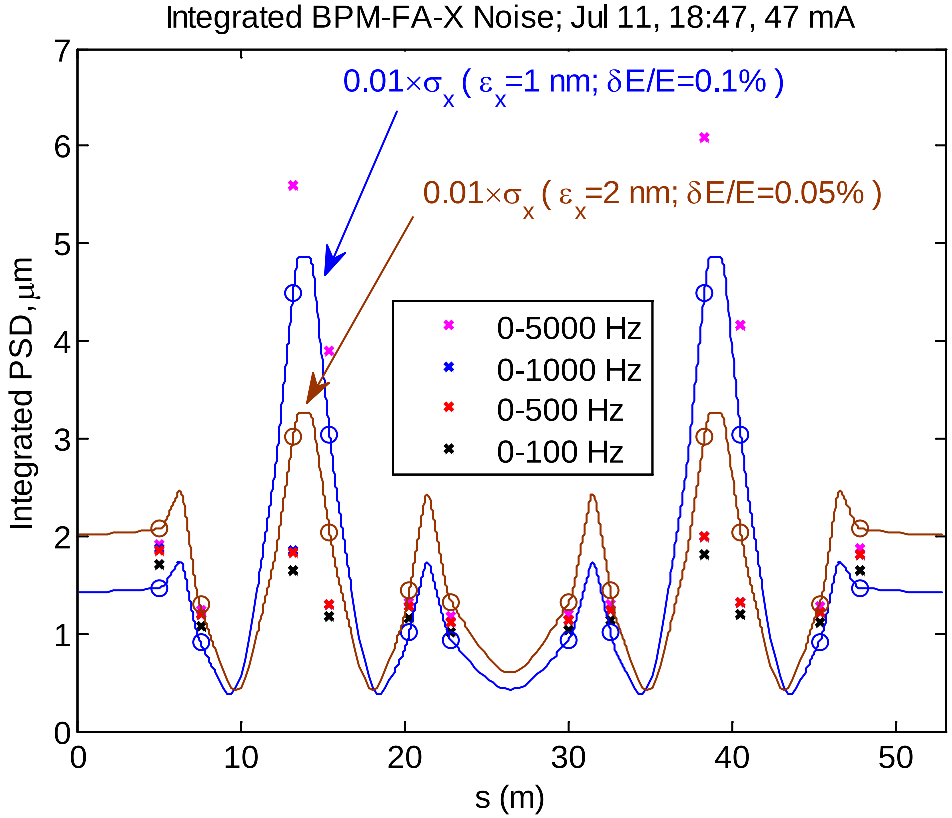
Circles: BPM locations

Crosses: Measurements

- Horizontal orbit stability is a lot better than the 10% beam size spec.

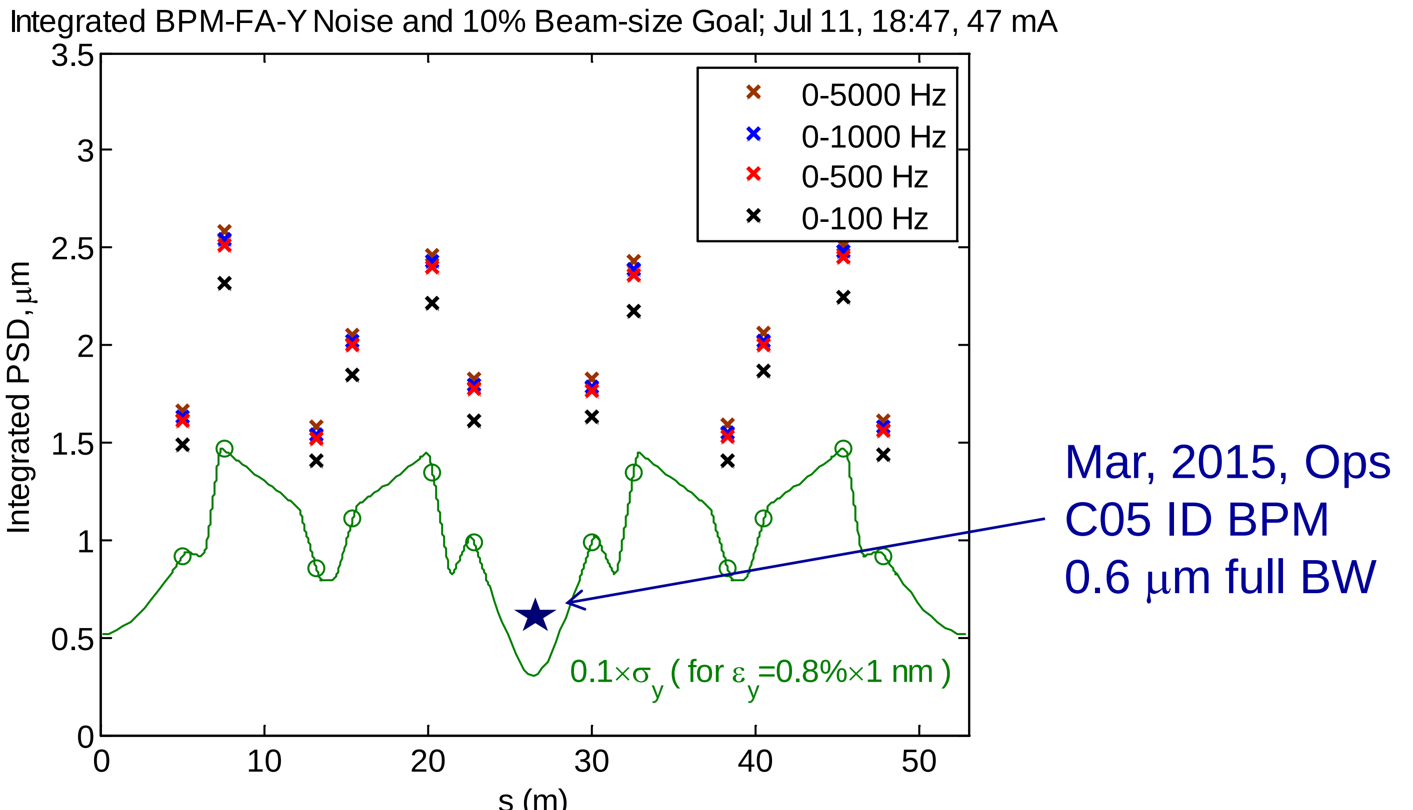
Horizontal Orbit Stability without Feedback

- Same data, x10 finer vertical scale



- Hor. orbit stability is at the level of ~1% beam size.
- Except for dispersion BPMs most of the noise is below 100 Hz.

Vertical Orbit Stability without Feedback

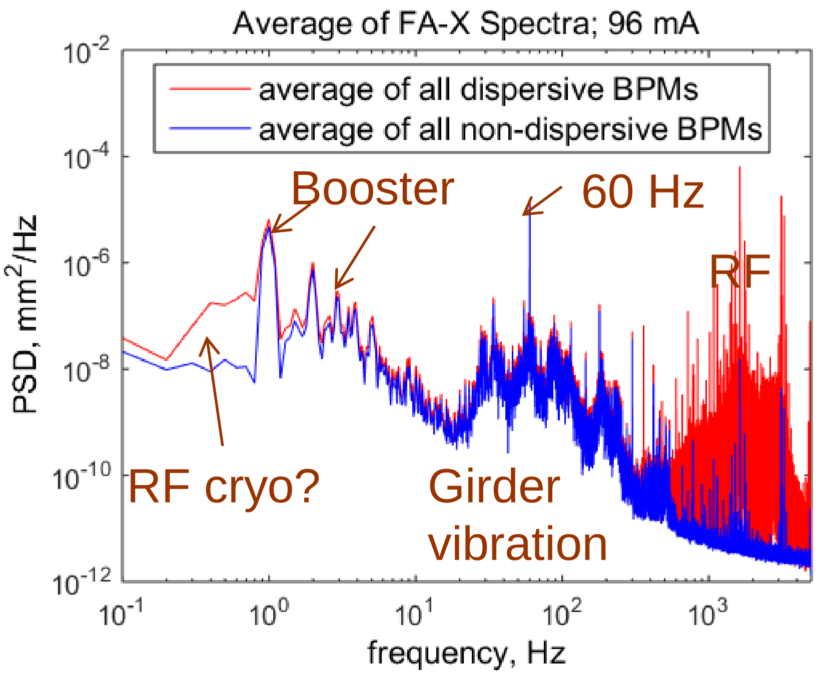


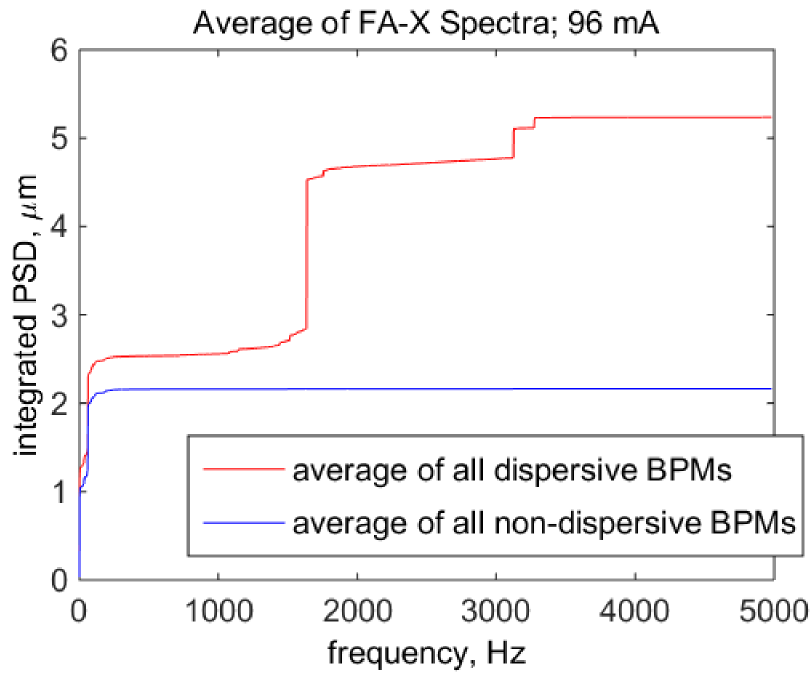
- Full BW vertical orbit stability is at the level of 20% of beam size.
- Need only a feedback gain of ~2 in 0-100 Hz BW to get to the spec.
- => a fairly simple feedback digital filter design should work.
- Integrated PSD approx. correlates with $(\beta_y(s))^{1/2}$.

Identification of Orbit Noise Sources

Short-Term Orbit Stability: Horizontal

- All 180 BPMs sampled for 10 sec at 10 kHz; orbit feedbacks off
- Plot ring-average BPM spectra (psd and integrated)

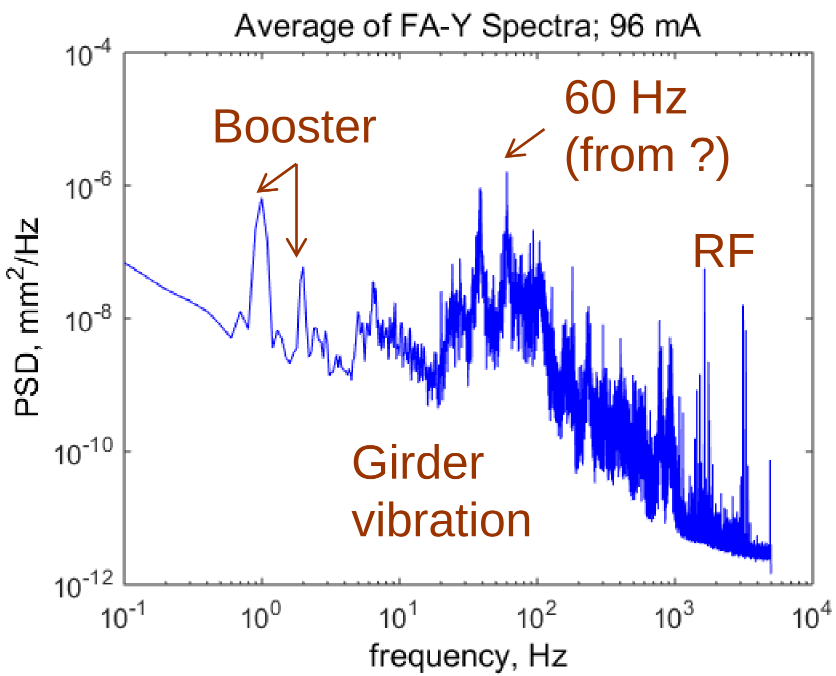


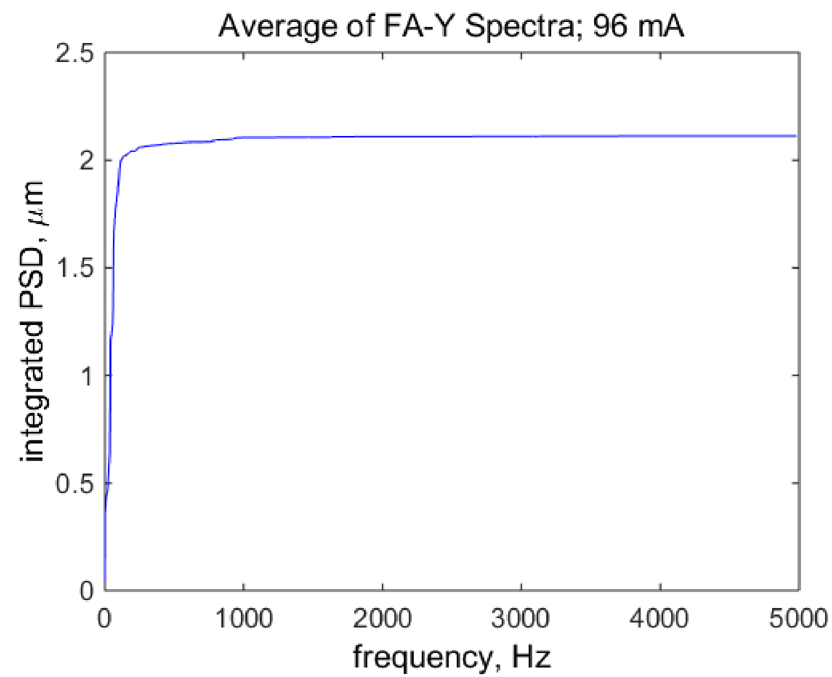


- Plenty of spectral features; but integrated levels are very small

Short-term Orbit Stability: Vertical

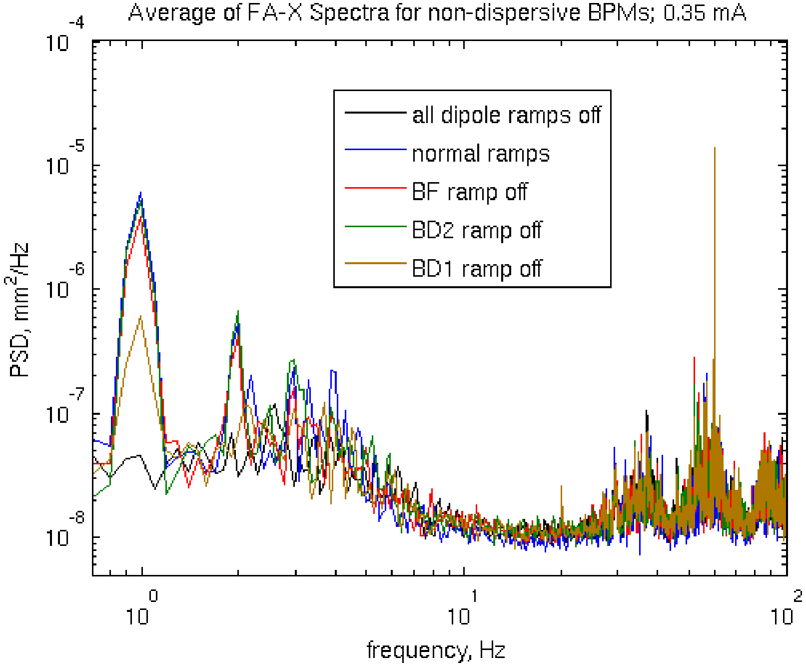
- Same plot for the vertical

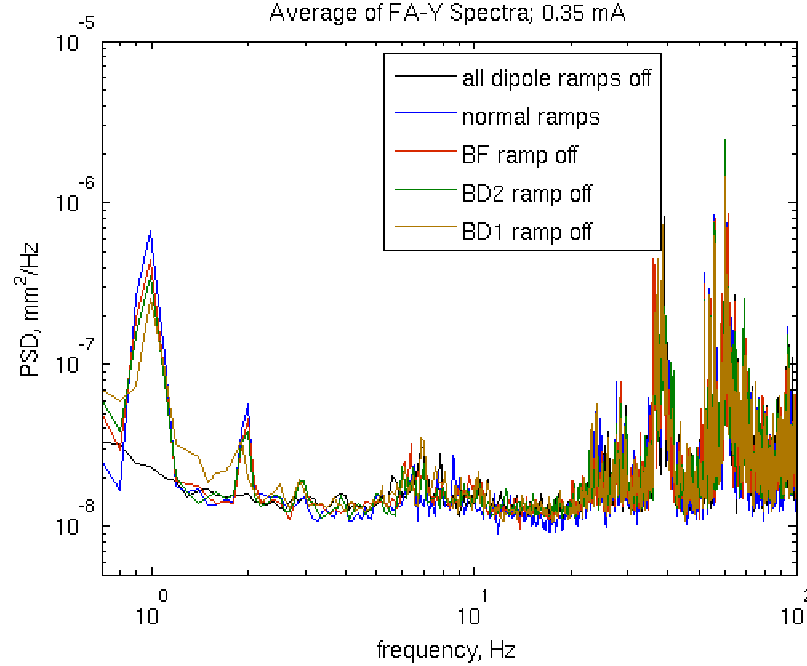




- Plenty of spectral features; but integrated level is very small

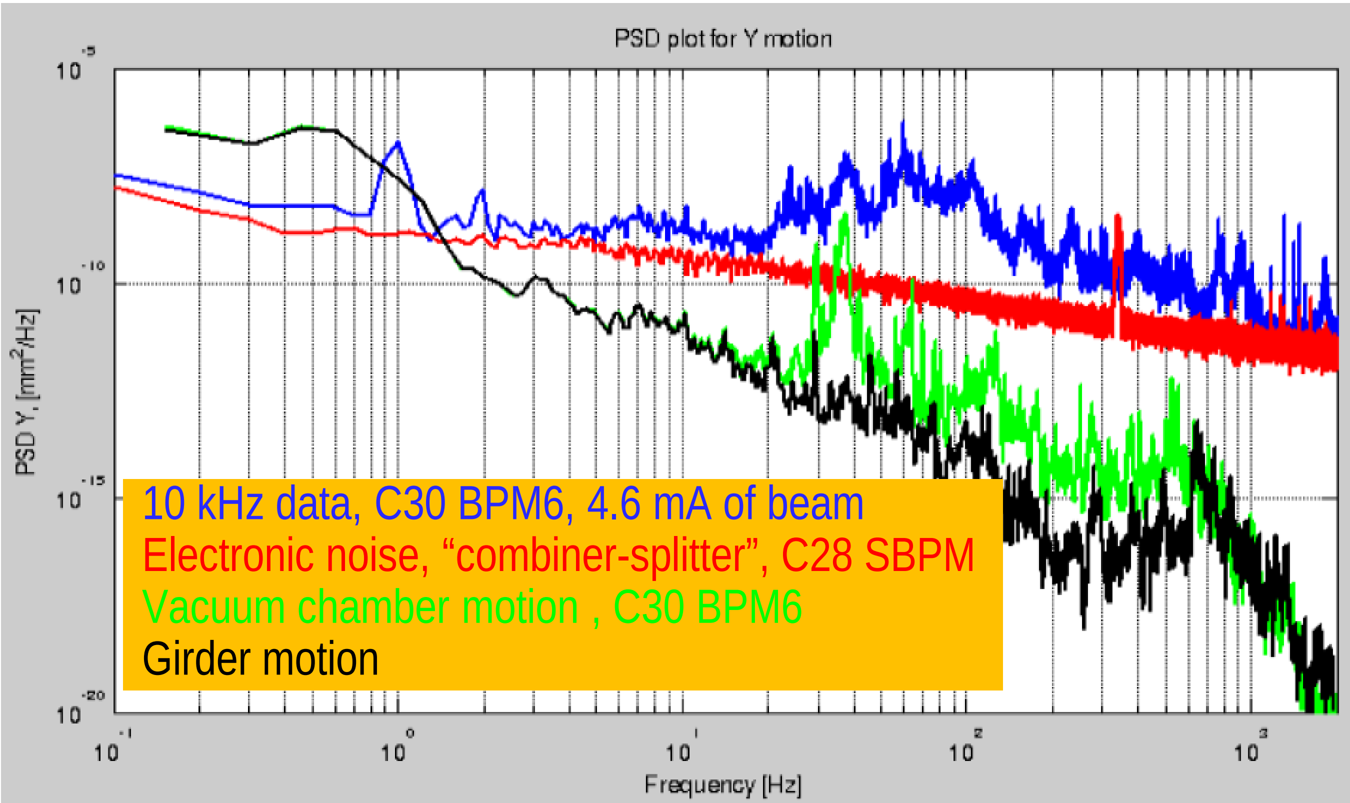
Booster Ramp Harmonics





- Booster magnet ramps (mainly BD1) induce 1 Hz orbit noise + harmonics
- Turning them all off (black curve) eliminates this noise completely
- This noise is reproducible, easily fixable by a simple feedforward system
- Or can be taken out by the FOFB.

Correlations with Vacuum Chamber and Girder Vibrations



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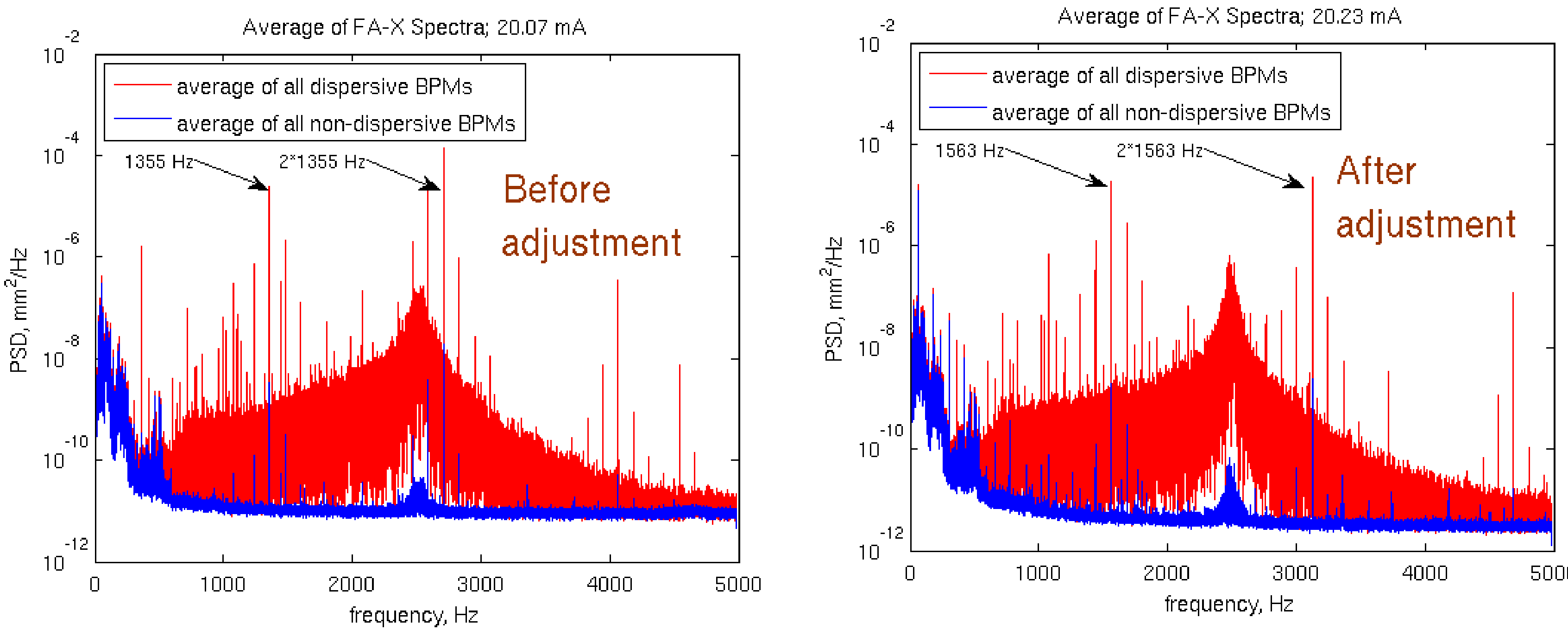
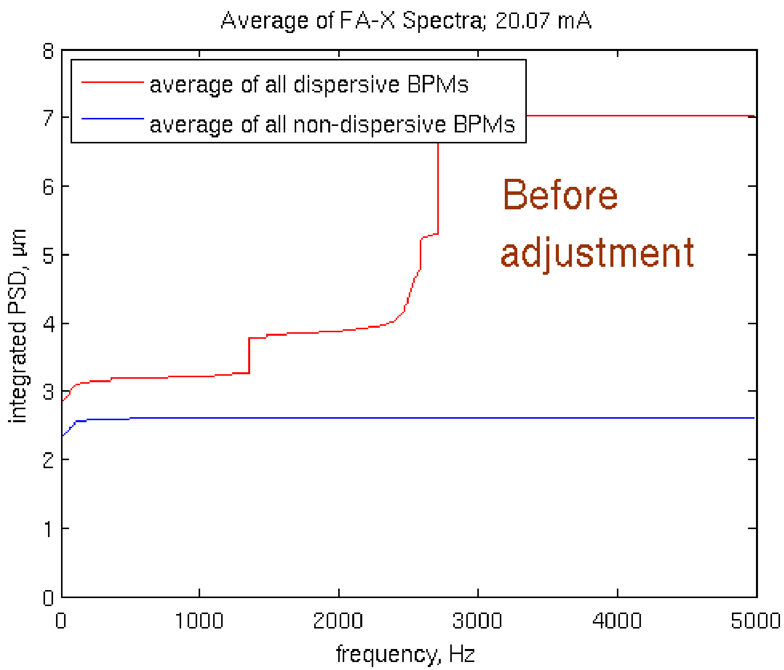
- All levels are pretty small
- Electronic noise << 4.6 mA beam except for the ~450 Hz peak (fixed now)
- Some correlation of mechanical motions and beam motion
- Some agreement to earlier mech. modelling and vibration measurements

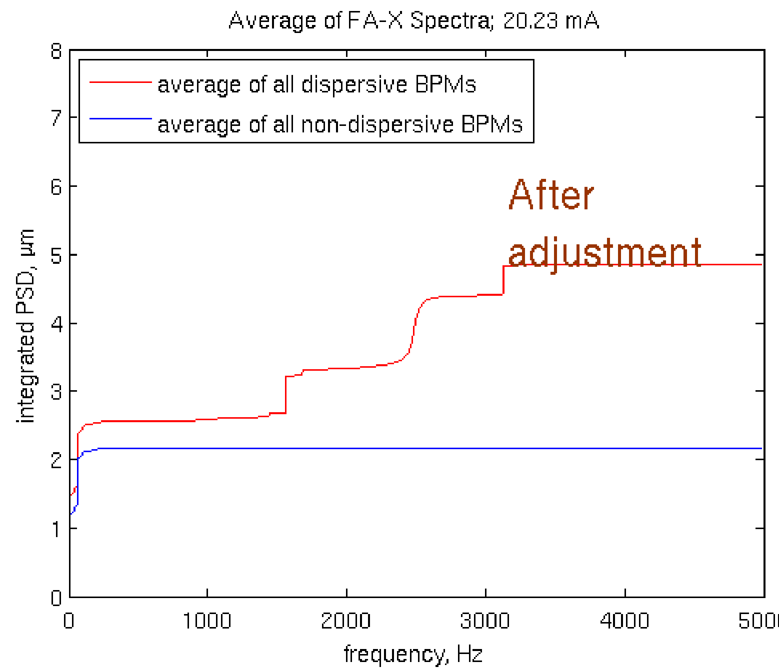
RF Noise



- Dispersive BPM noise is dominated by RF, but it is still small!
- Recent adjustment of the switching frequency of the RF HVPS to have synchrotron peak in a to "quieter region" i.e. between the switching frequency sub-harmonics (112 kHz/86 modules)
- Strongest switching frequency lines are down by a factor of ~6

RF Noise Cont'd



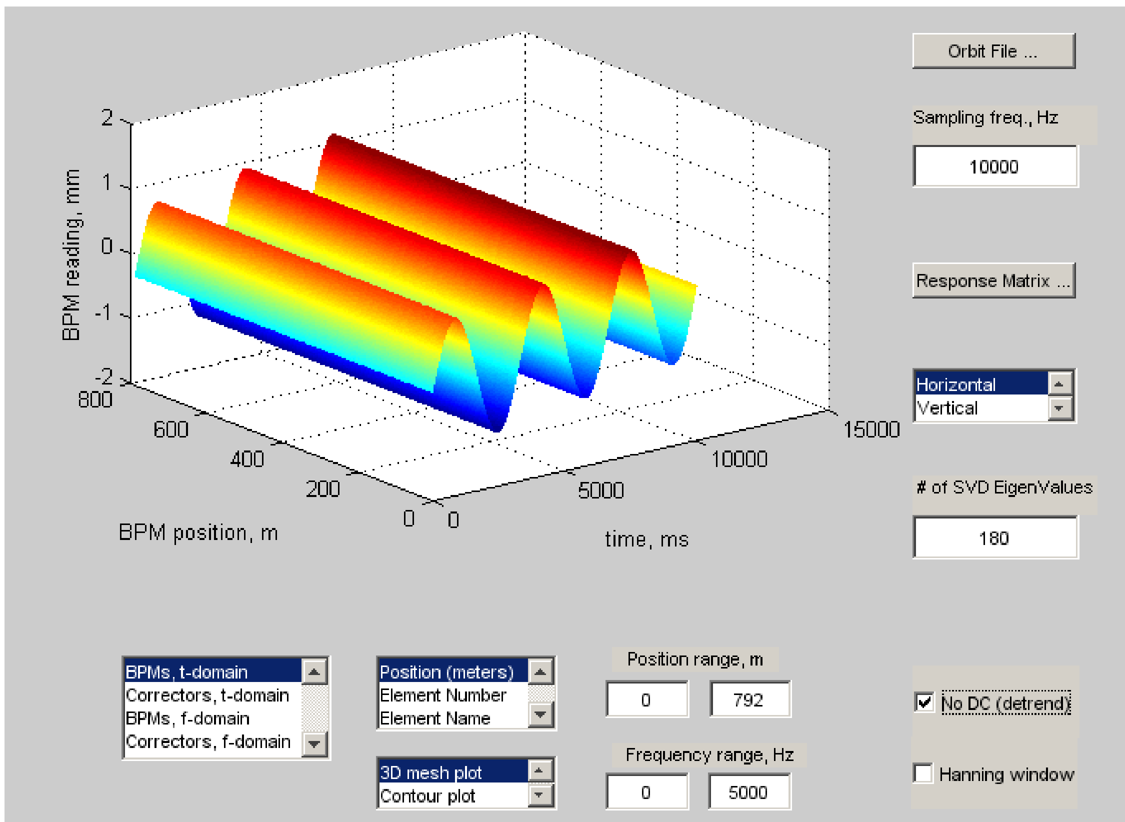


- The noise is a very small percentage of beam size
- The noise does not directly affect the (ID) users
- It cannot be cured by FOFB (frequency too high !)
- May need to revisit once IR beamlines come online

The Source of 60 Hz

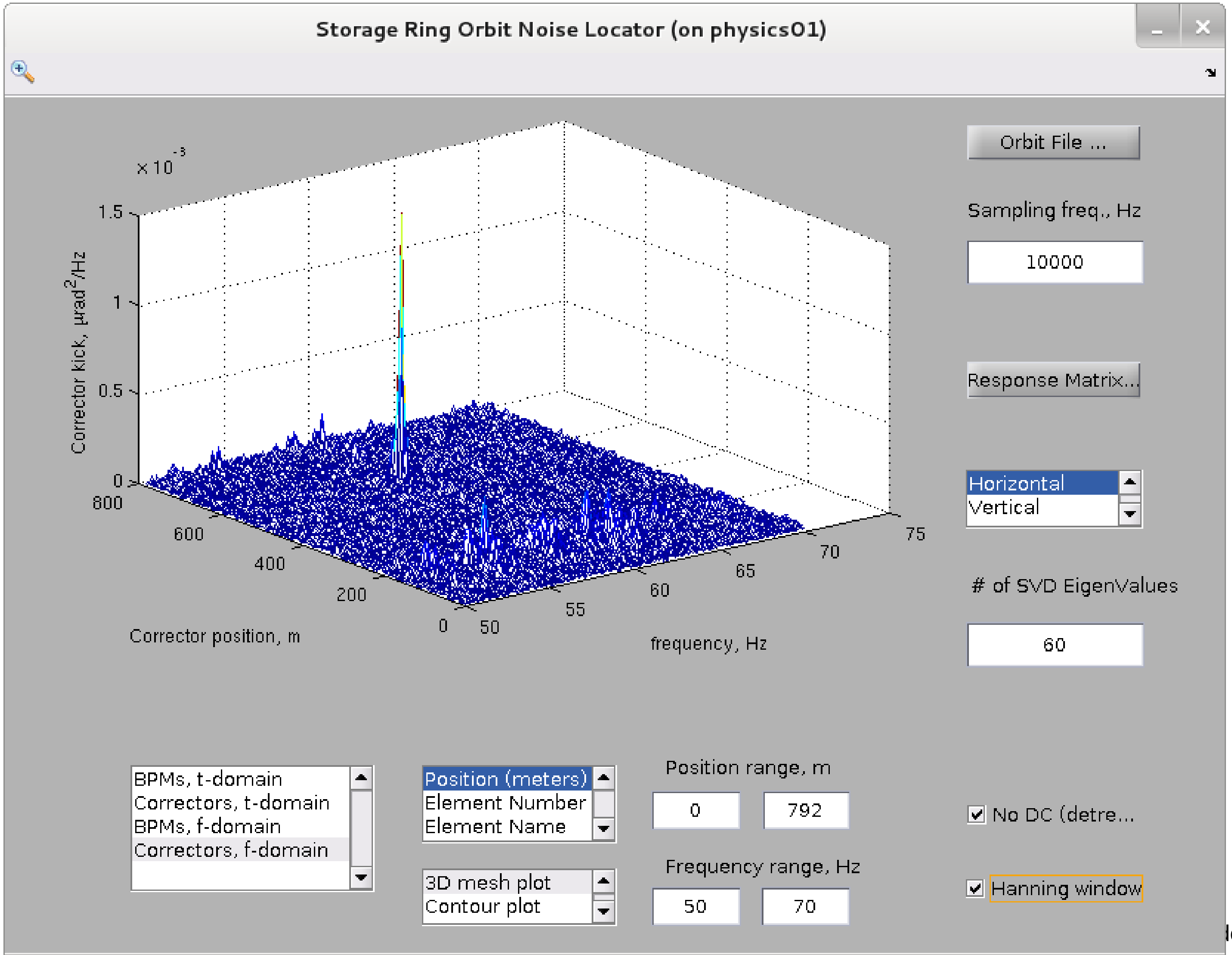
Noise Locator Tool for NSLS-II

- Uses Matlab Middle Layer by Greg Portmann
- Input is any sampled orbit data file, usually FA (10 kHz), or SA (10 Hz)
- The tool does display and analysis only (no machine control)
- Self-explanatory GUI interface



Found with the Noise Locator Tool

- Most of the 60 Hz noise coming from one single location, s~580 m

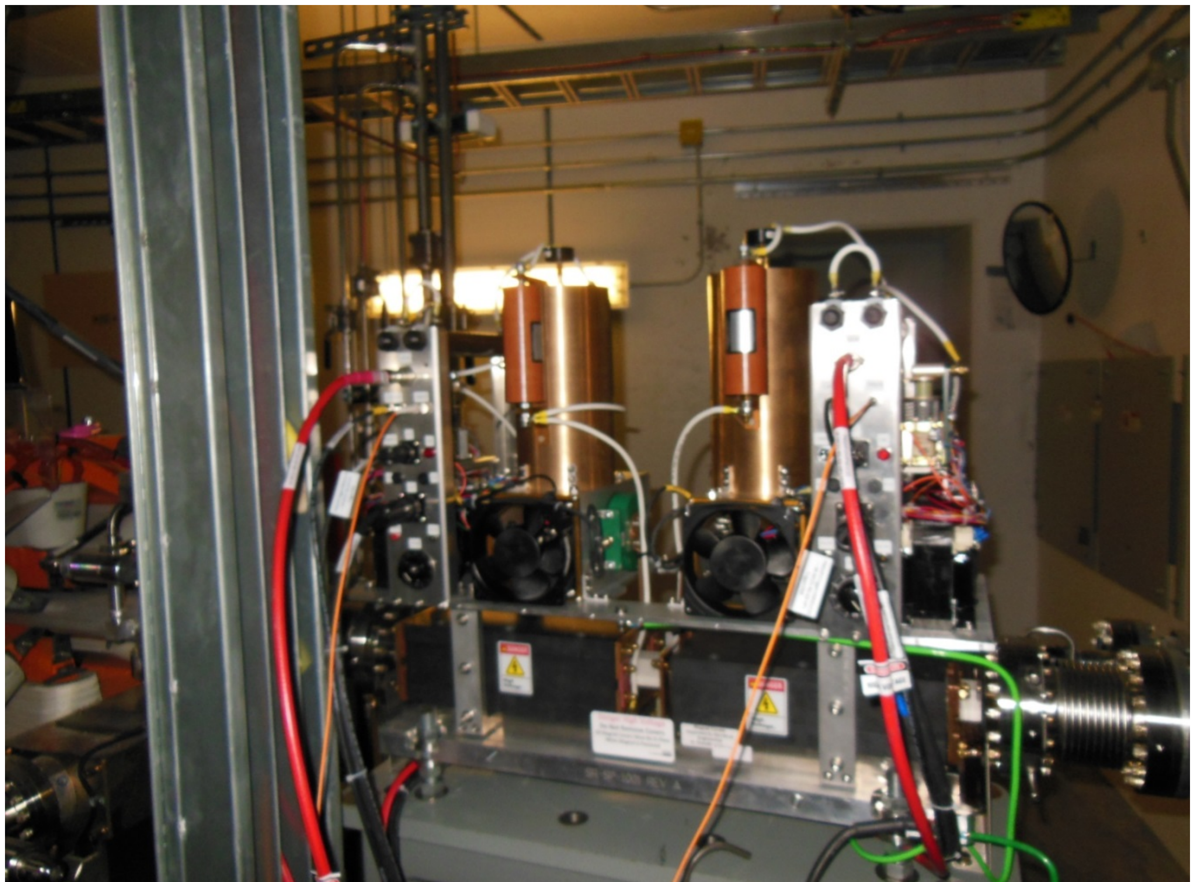


Pinger Magnets in the Ring

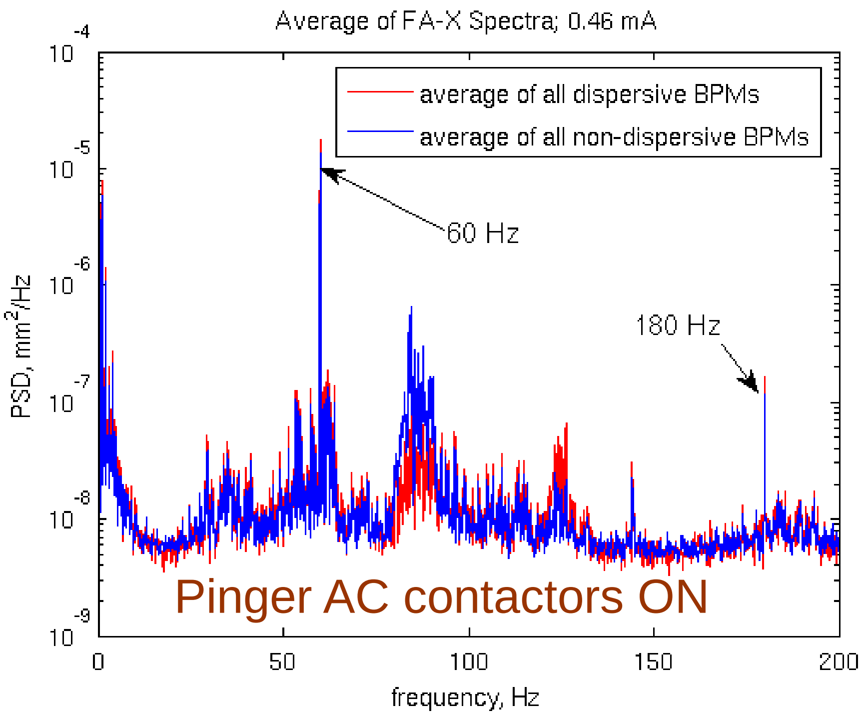
- Pinger magnets are located at s=577.17 m (h) and 577.54 m (v)

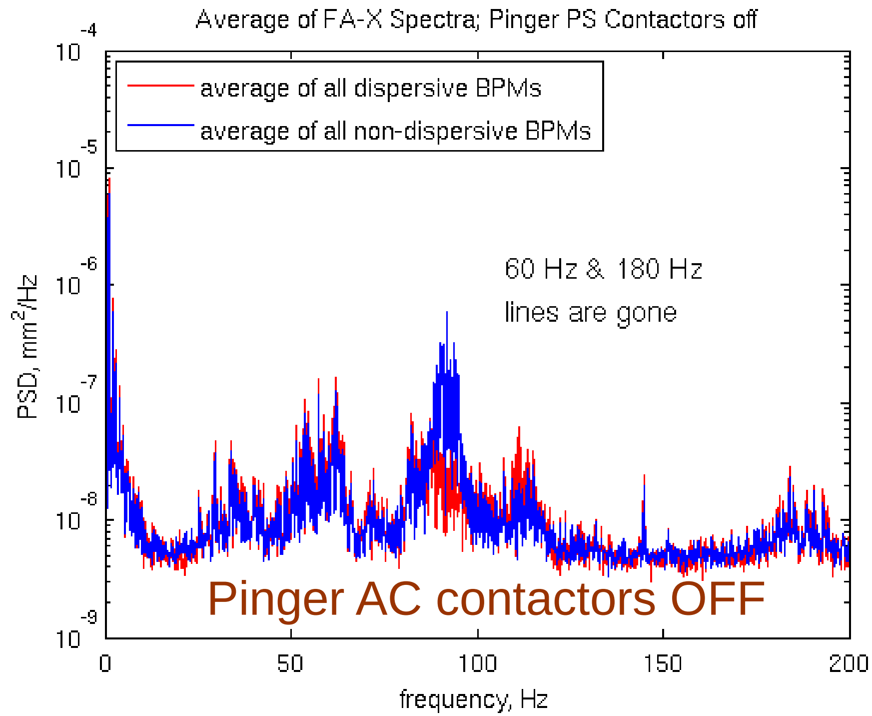
Pinger Magnets in the Ring

- A likely source of 60 Hz is one of the transformers close to the beam pipe
- Transformers are on even when high voltage is off (and no beam pinging)



Turning Pinger AC Contactors OFF…



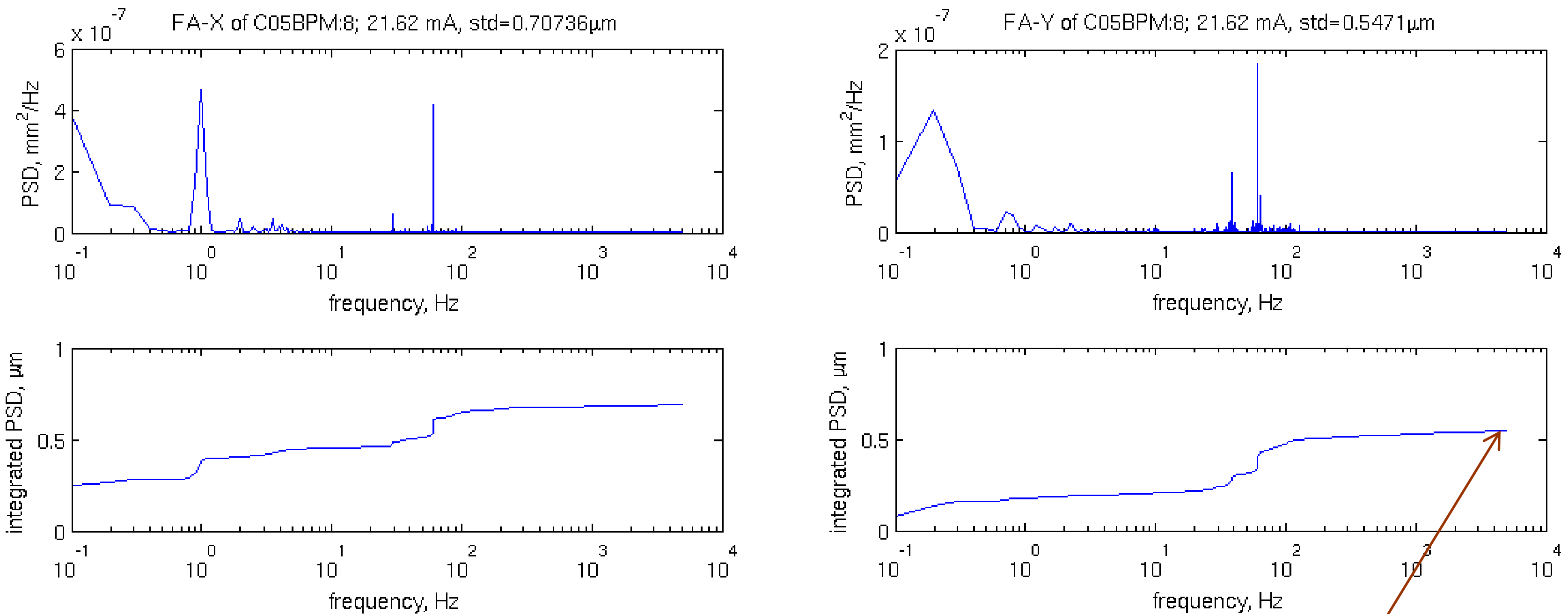


- … kills the 60 Hz and its harmonics
- This is the simplest cure as we don’t use pingers during ops anyway
- However, users don’t seem to notice this noise so far (so we often ran with pinger AC contactors on)

Back to Overall Orbit Stabitliy

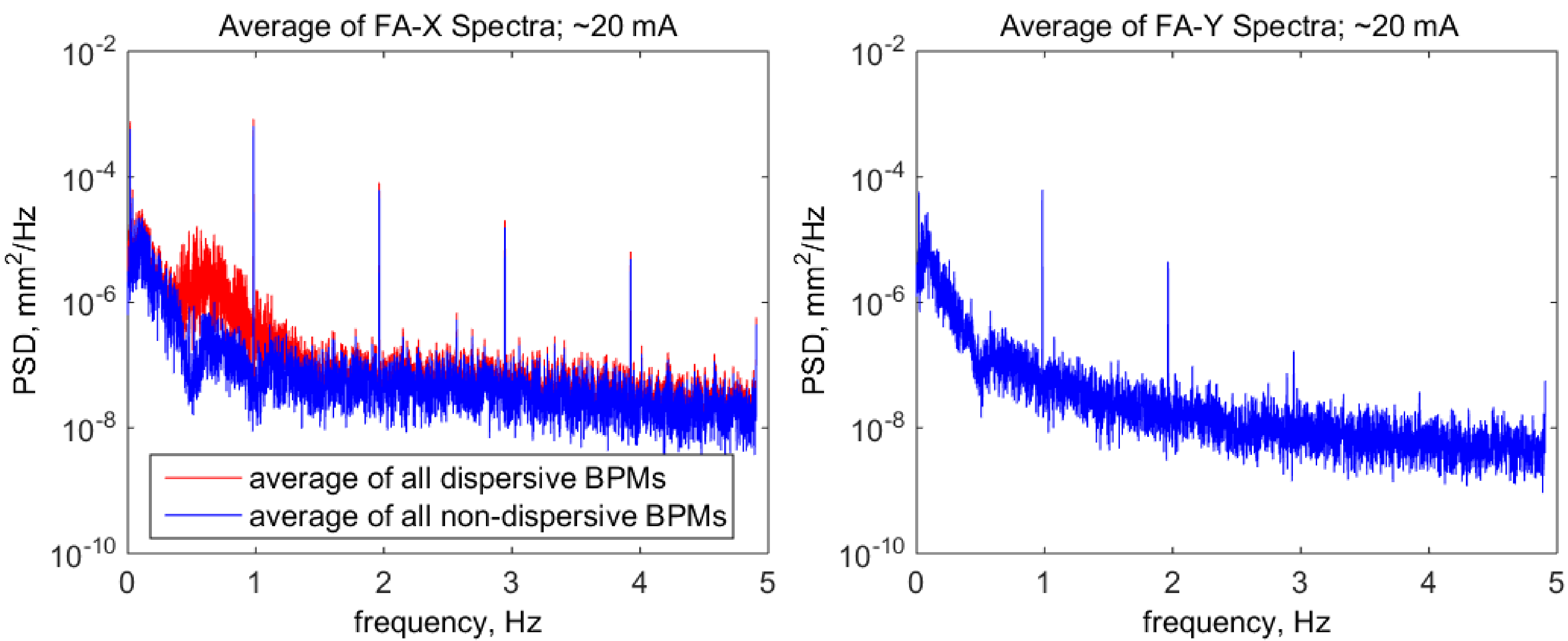
Short-term Orbit Stability: ID BPMs

- 3/26, Ops with SOFB, Vertical ID BPM; Cell 5 center



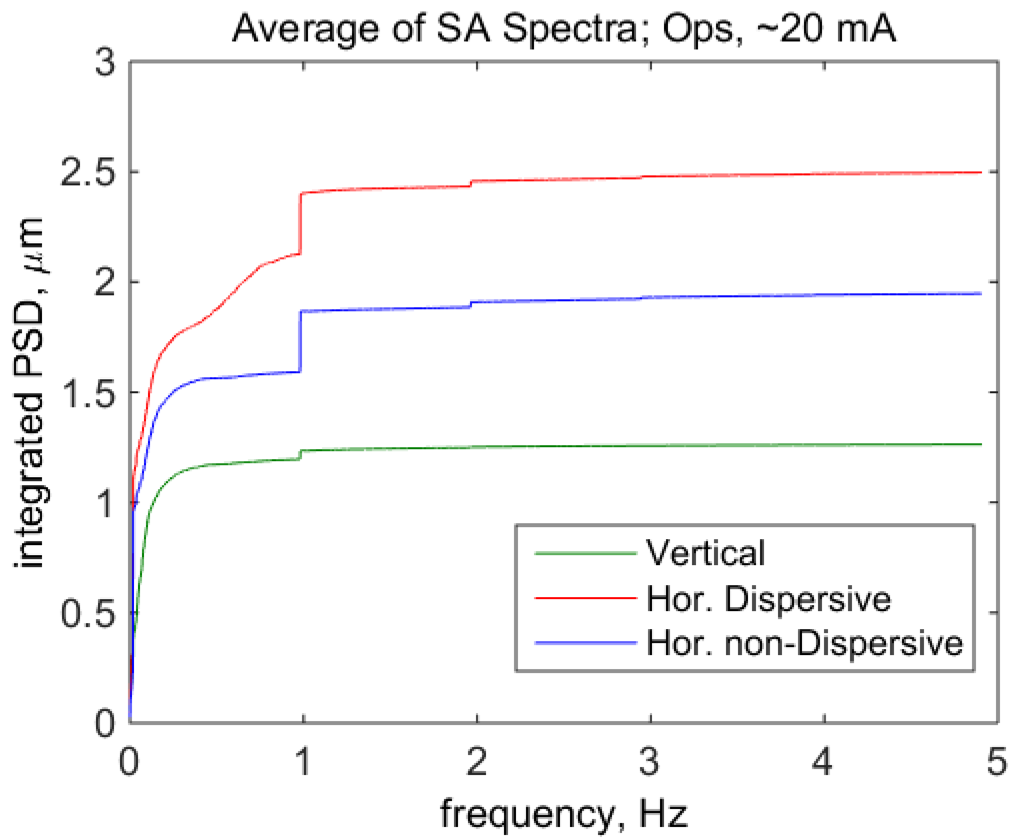
Less than 20% of the design beam size

Medium-term Orbit Stability: First Look at Buffered SA Data



- 10,000 points (= 16.7 mins) of 1 Hz orbit data from 180 RF BPMs
- Slow Orbit Feedback ON
- Not much spectral structure; just booster harmonics and “RF cryo?”

Medium-term Orbit Stability: First Look at Buffered SA Data Cont'd

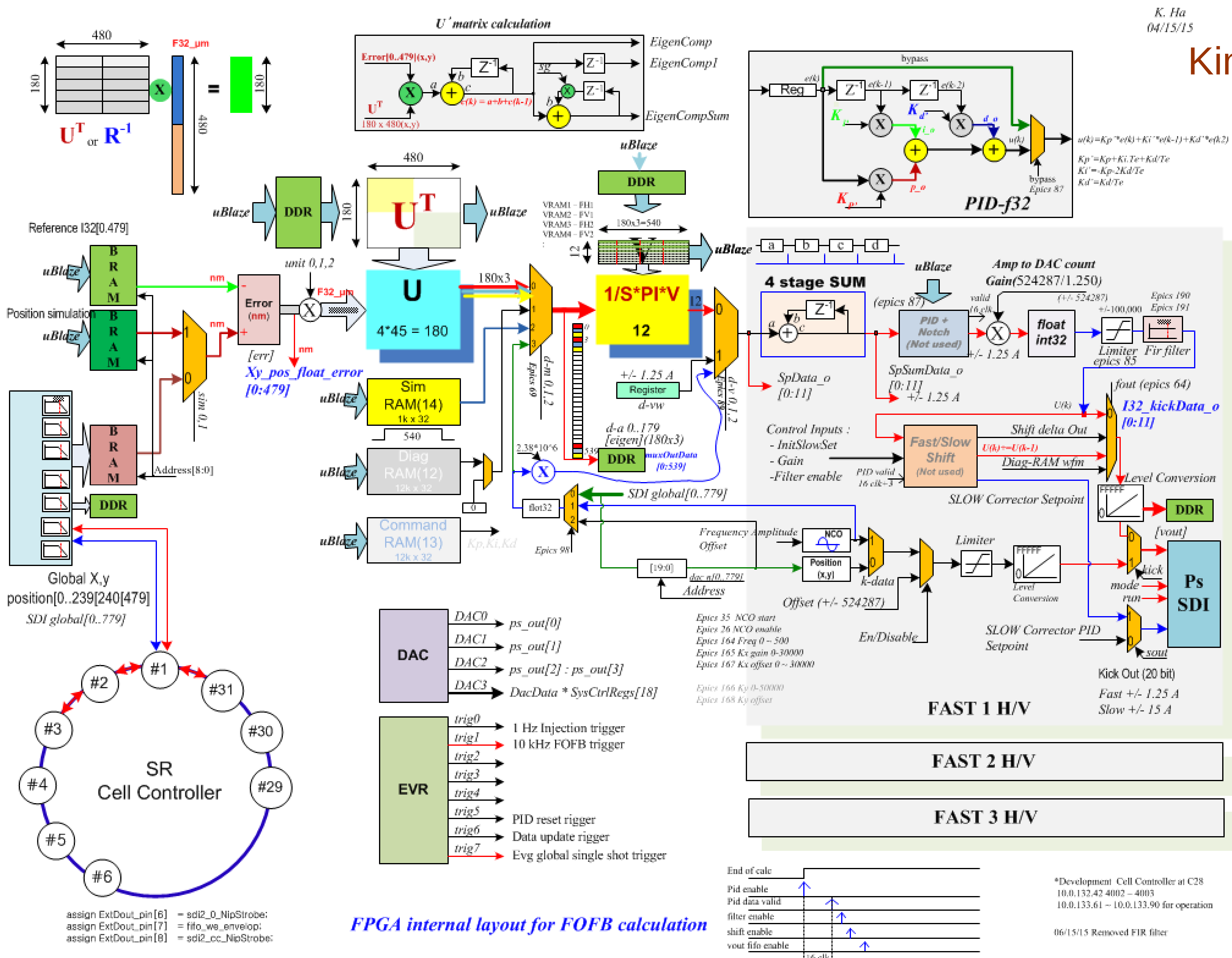


- Integrated PSDs for the same data
- Levels are pretty low

Fast Orbit Feedback

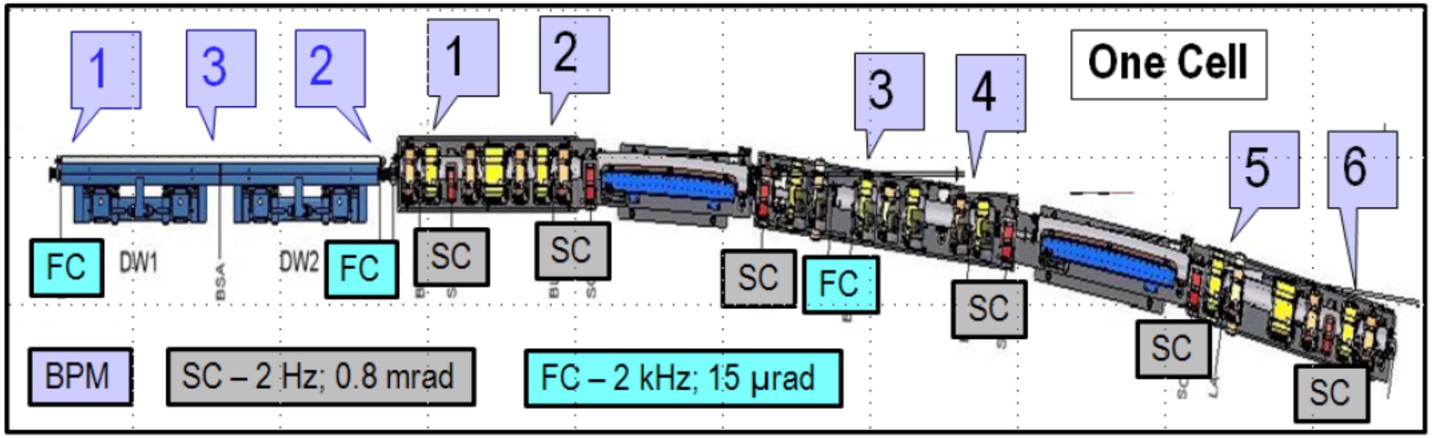
Fast Orbit Feedback Diagram

Kiman Ha



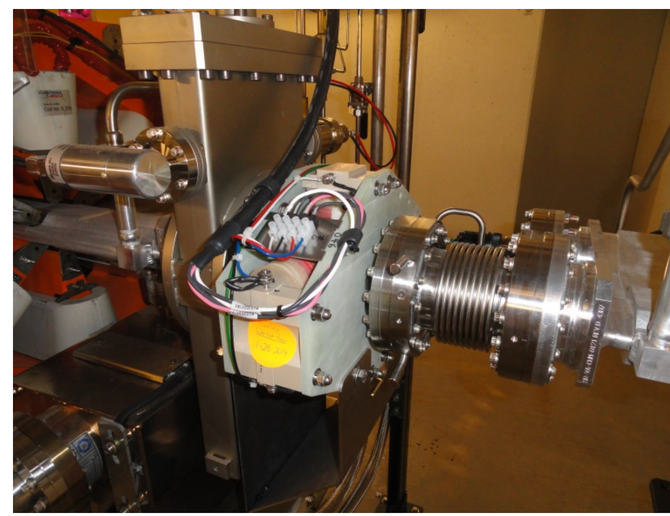
FPGA internal layout for FOFB calculation

Fast Orbit Feedback



Om Singh et al. IBIC 2013

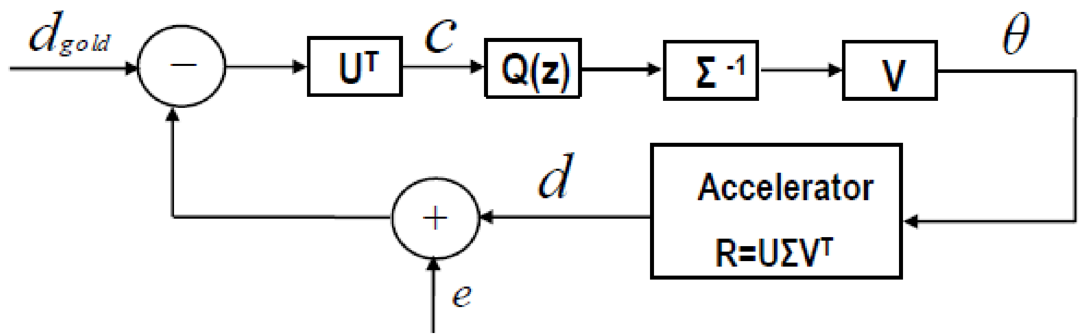
- 180 BPMs in each plane
- 90 fast correctors / plane with an option to offload accumulated kick effort to (strong) slow correctors
- Standard SVD algorithm
- Individual PID coefficients for each eigenvector

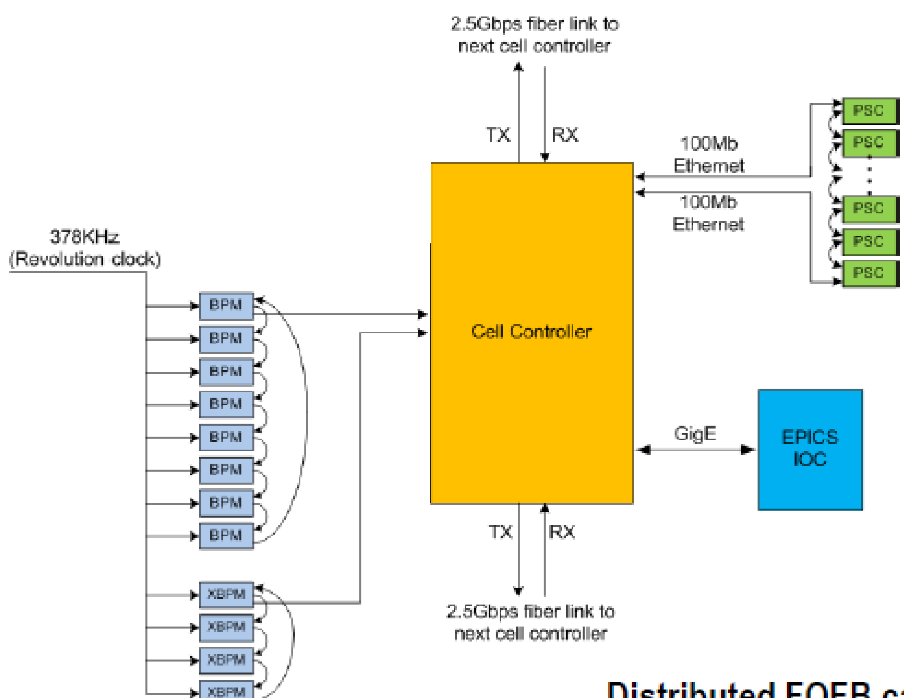


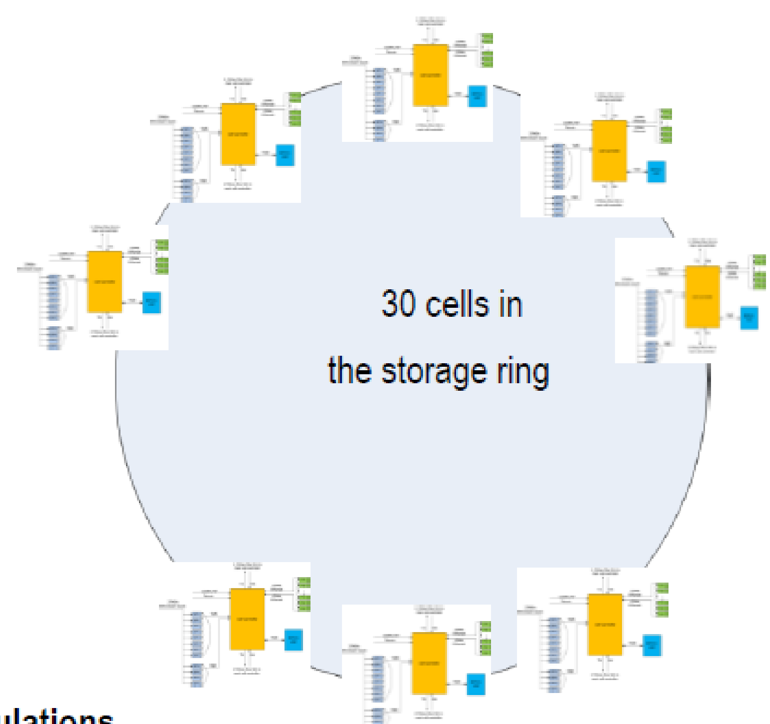
Fast Corrector

Fast Orbit Feedback

Yuke Tian
Li-Hua Yu

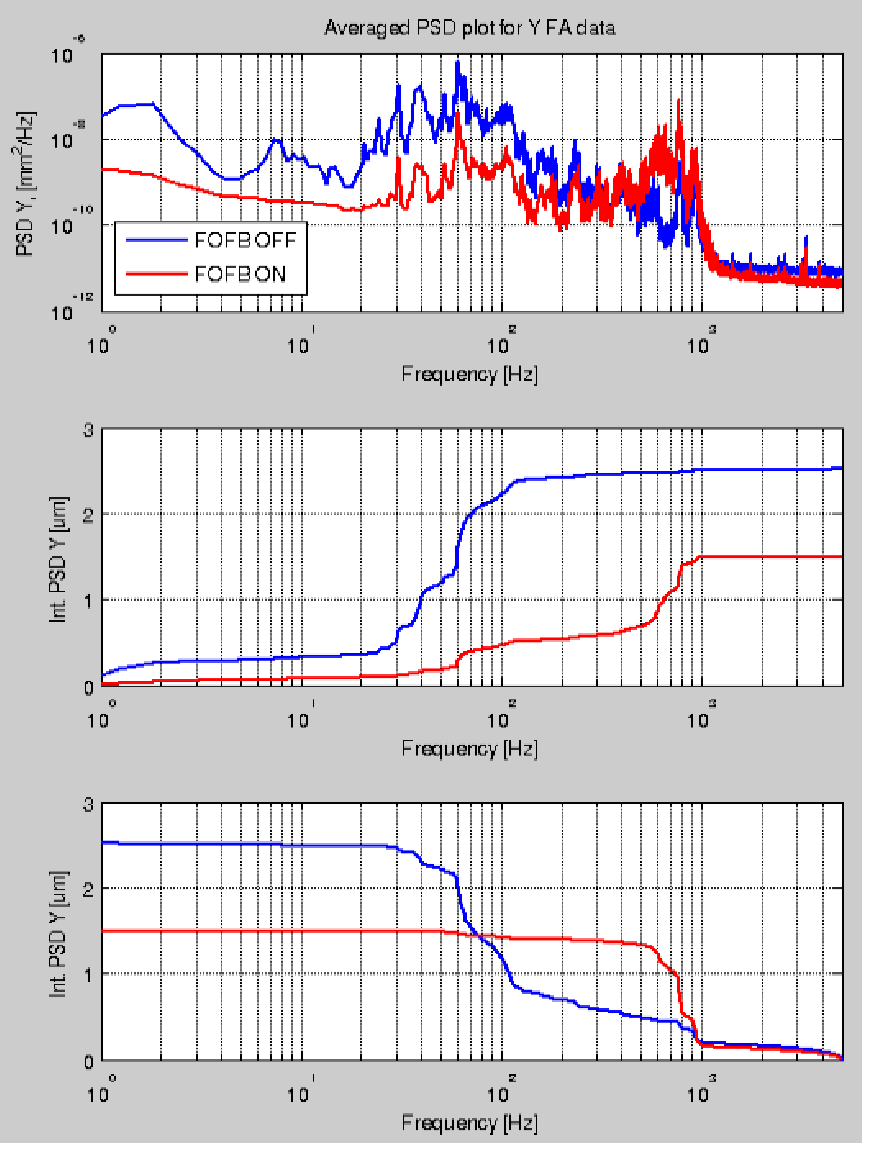






Distributed FOFB calculations

Stability with Fast Orbit Feedback



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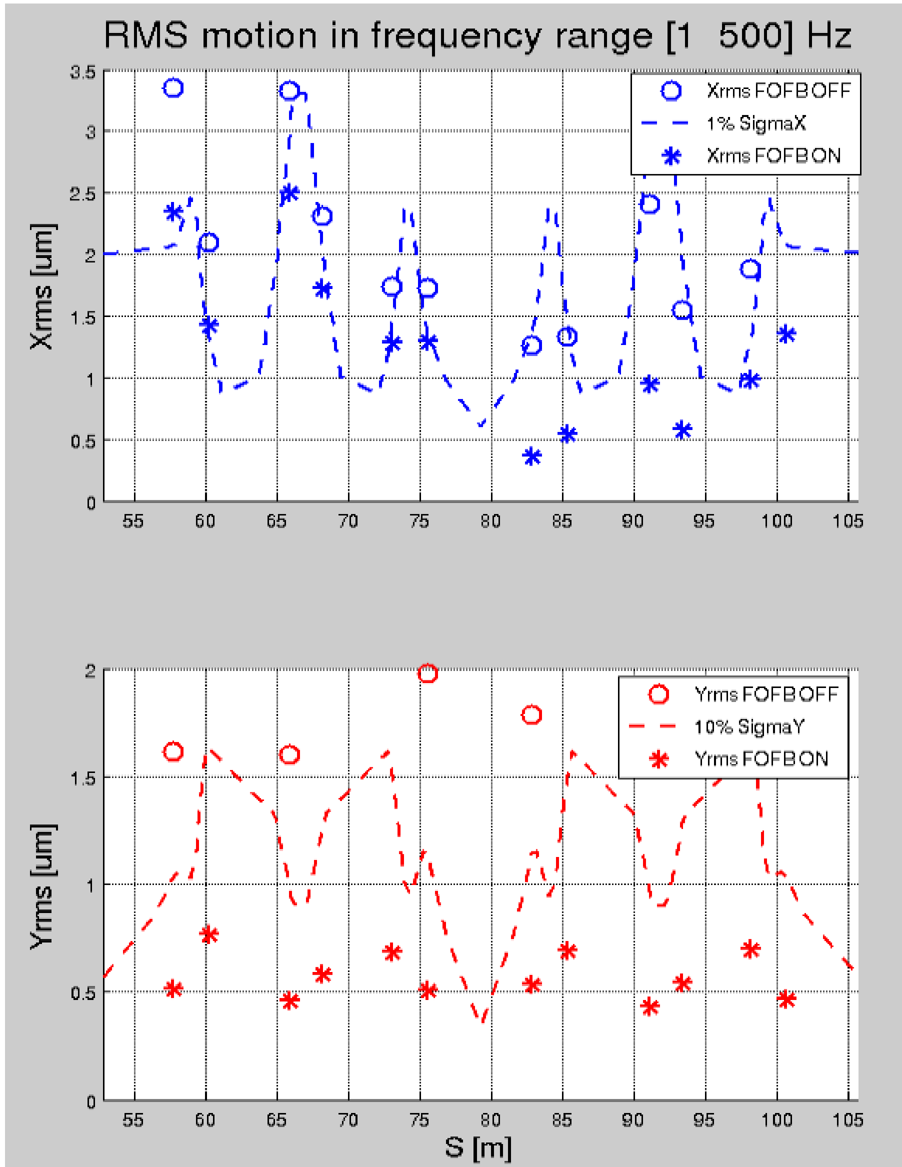
Stability with Fast Orbit Feedback Cont'd



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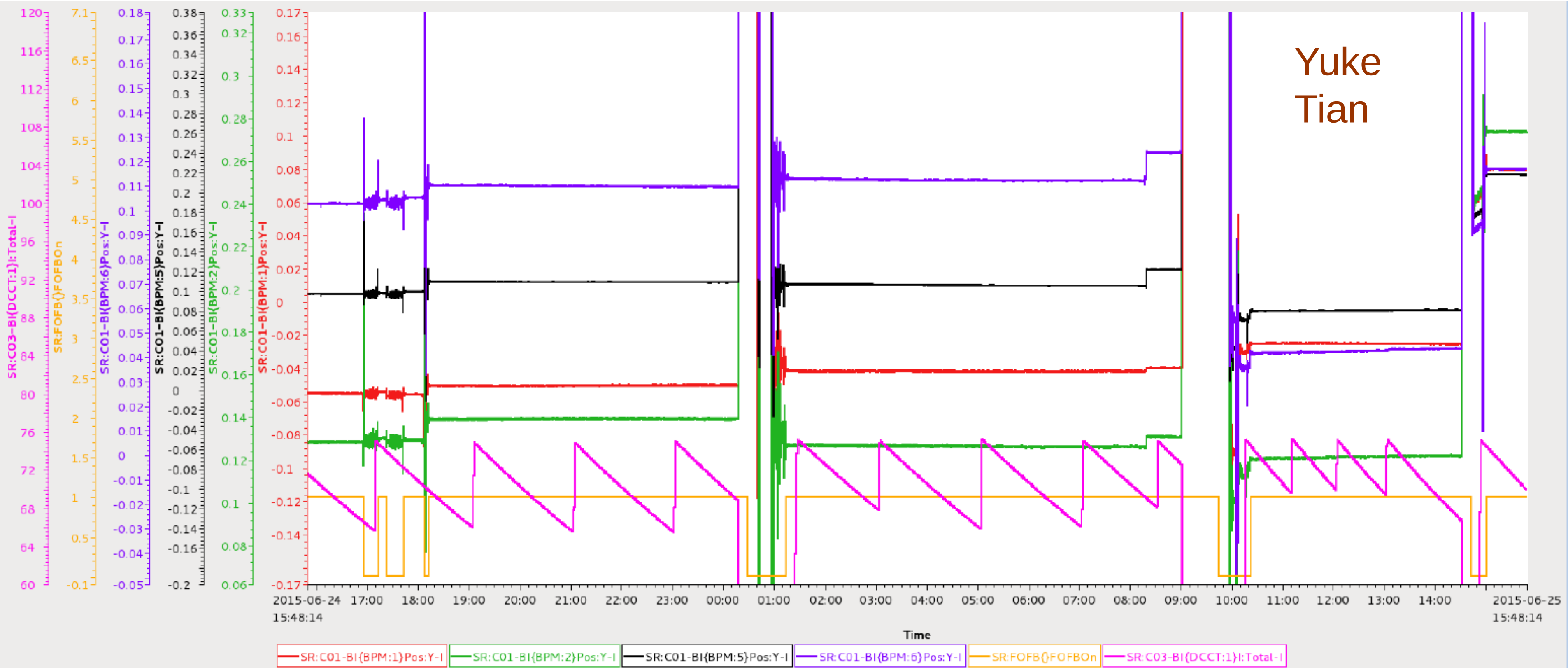
Long Term Stability with FOFB



- 4 non-dispersive vertical BPMs shown during "75 mA Ops" with FOFB
- Long term drift is less than 1 μm
- Long term drift in the horizontal (not shown) is less than 5 μm
- Further improvement is expected with top-off and FOFB optimization

Conclusions and Future Plans

- Even without orbit feedbacks NSLS-II orbit stability is quite good, thanks to the meticulous design efforts.
- Short term stability is brought within 10% of beam-size (sub-μm in the vertical) by using a fast orbit feedback system.
- Major noise sources have been identified and understood, especially the short-time scale ones.
- Longer term stability was less studied due to lack of time and rapid machine development. Typical orbit drifts in 8 hr period at the ID source points are sub-μm in the vert., single digit microns in hor.
- Further improvement is expected from top-off operations to start soon.
- Other developments will include commissioning X-ray BPMs, further optimization of orbit feedbacks, and joint studies with the users.

Thank you