SPEAR3 Fast Orbit Feedback and Beamline Dynamic Steering

Presented to Beam Stability Workshop, LBL
11/1/2018

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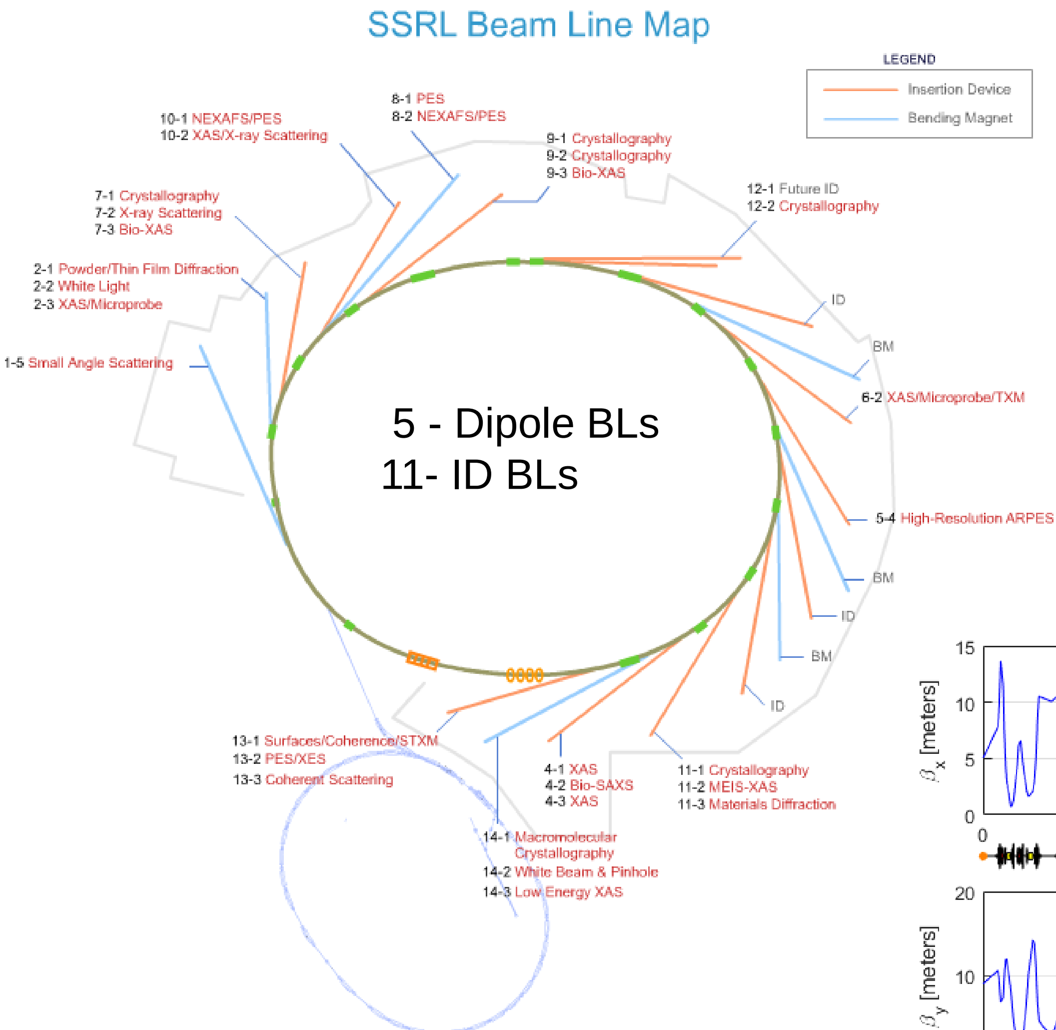
Outline

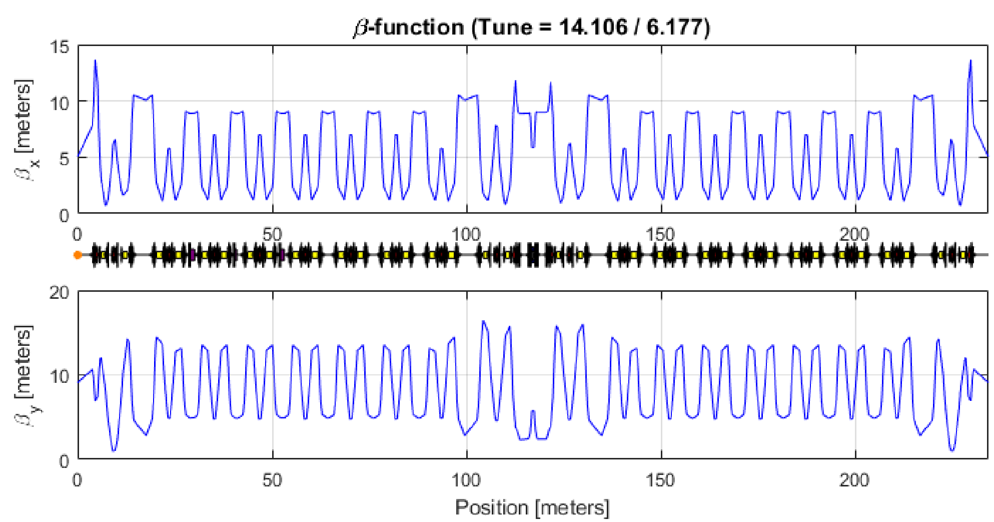
- Fast orbit feedback (FOFB)
- Beamline dynamic steering (BLDS)
  - Feedback
  - Manual steering
- Orbit stability in SPEAR3
  - Long term stability (seasonal and diurnal)
  - Slow orbit drift
  - Fast orbit disturbances

SPEAR3 overview

SLAC



Parameters	
Circumference	234 m
Emittance	10 nm
Beam current	500 mA
Top-off interval	5 min
Lifetime	7 hrs

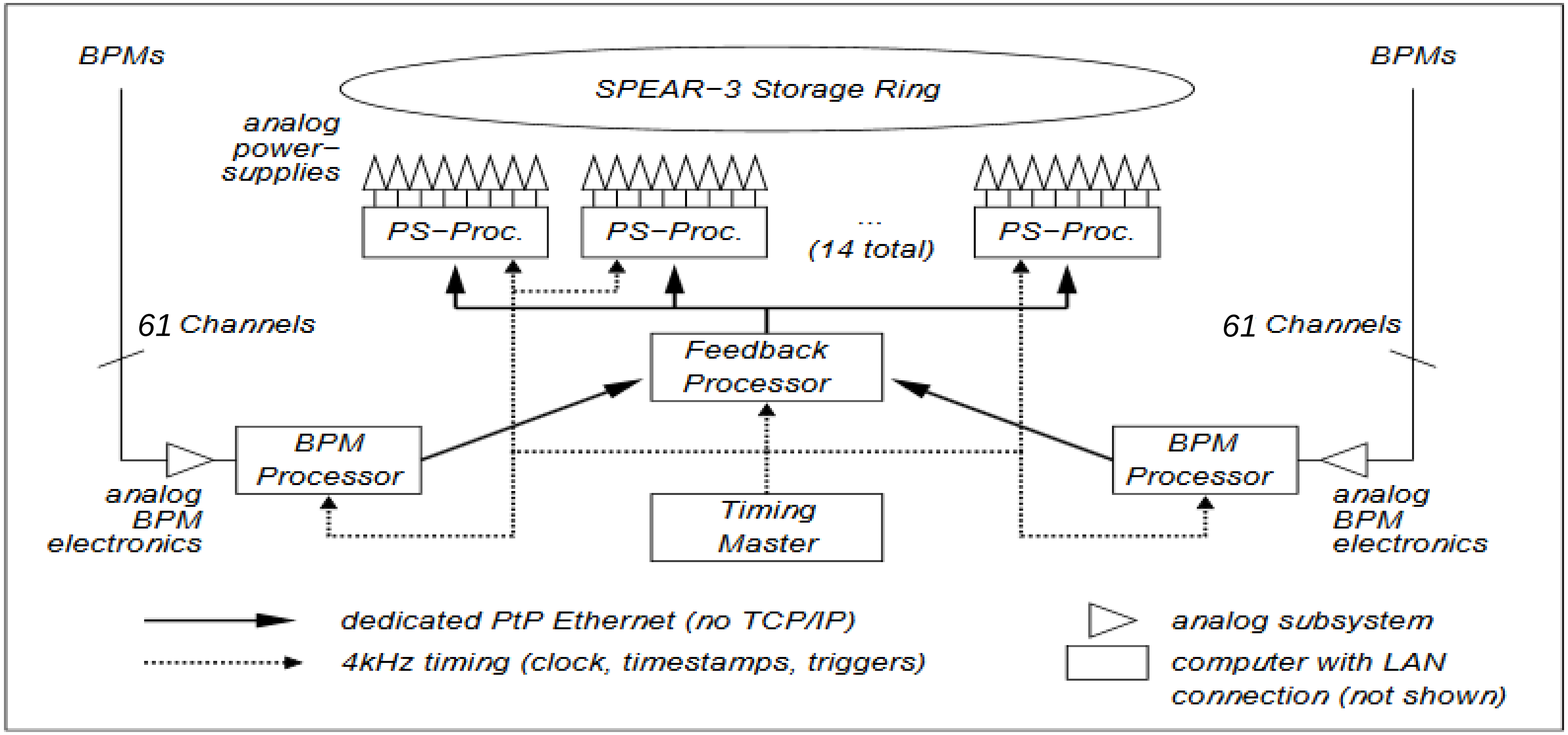


X. Huang, SPEAR3 Orbit Stability

Fast Orbit Feedback (FOFB) and Beamline Dynamic Steering (BLDS)

Fast orbit feedback in SPEAR3

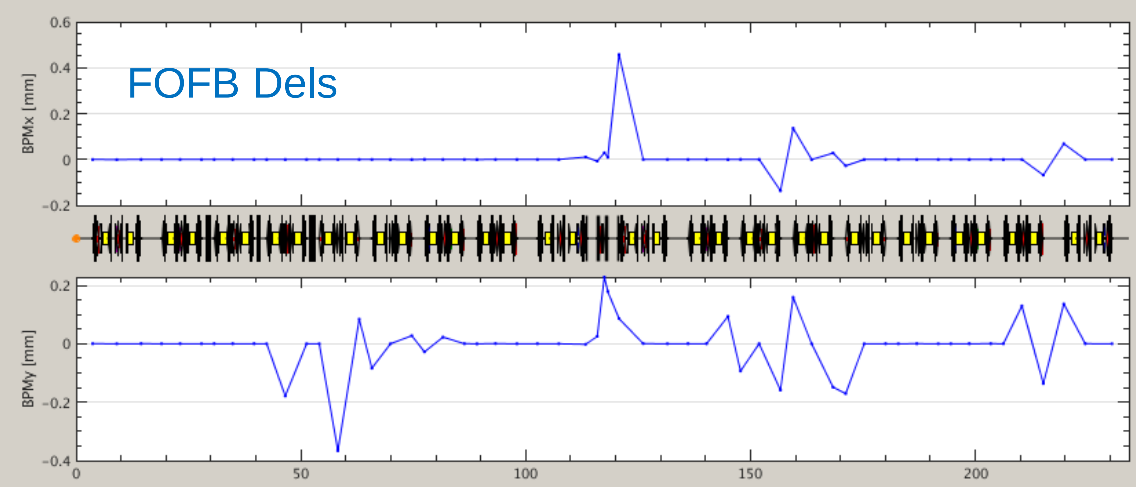
- 57 Bergoz BPMs
- 58 horizontal correctors, 56 vertical correctors
- Operates at 4 kHz



A. Terebilo, T. Straumann, EPAC'06

Orbit target

- Orbit target = Golden orbit + Dels
- Golden orbit: a static target downloaded to the feedback processor
  - Golden orbit is set to the BPM offset found by beam-based alignment for most BPMs.
- Dels: a dynamic component (PVs used to adjust the target on the go)



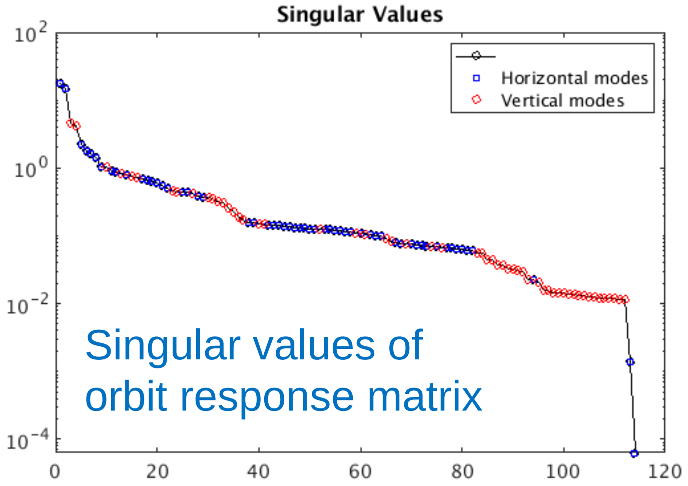
Feedback algorithm

- Feedback algorithm
  - Proportional-Integrator (PI) control for the eigen-modes of orbit response matrix

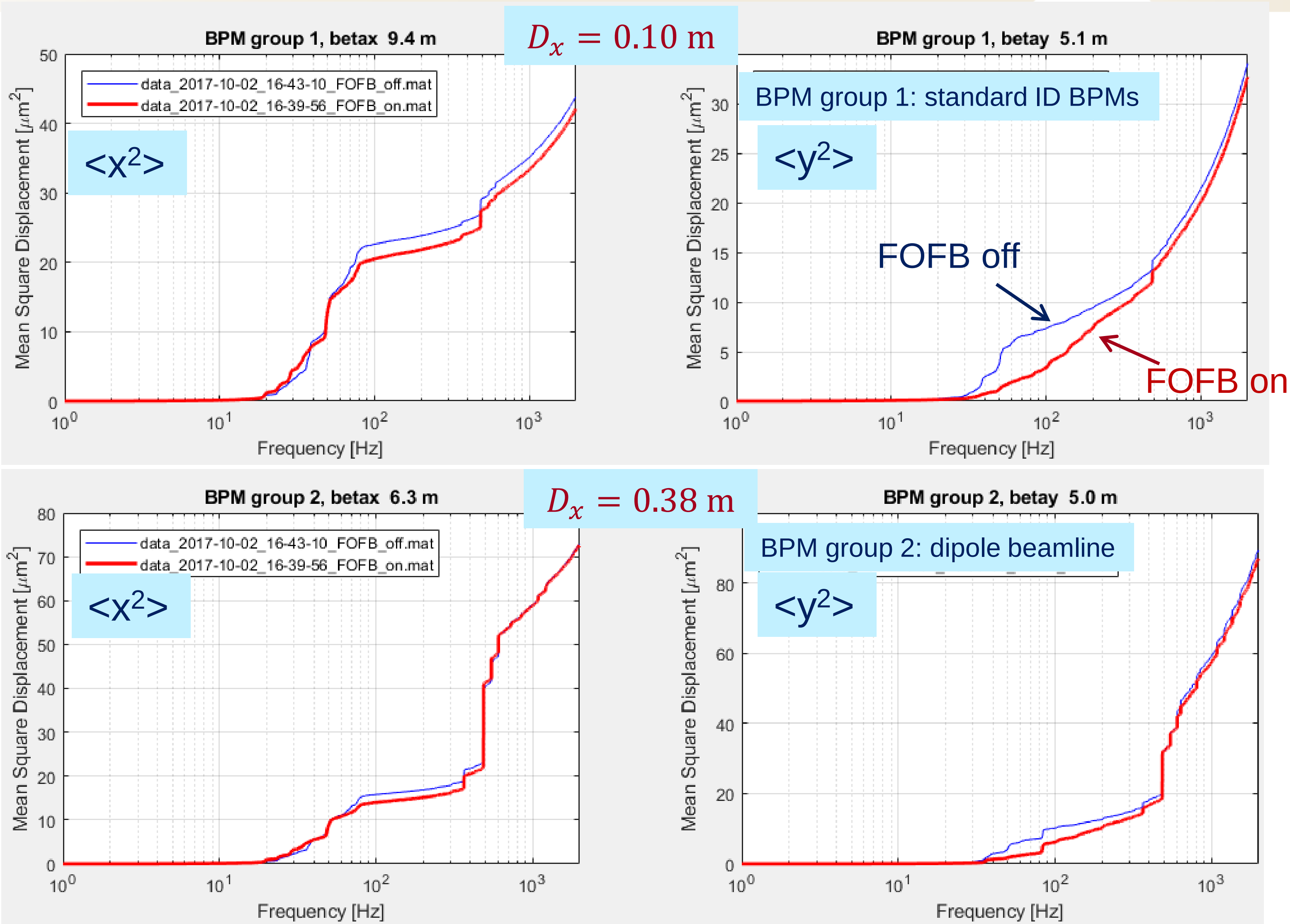
$$R = USV^T \qquad \Delta\theta = VS^{-1}U^T\Delta x$$

  - Feedback processor computes $(S^{-1}U^T)\Delta x$ and send the results to the power supply processors.
  - PI coefficients are adjusted for each mode. All P-coefficients are zero.

The I-coefficients are set according to the SV of each mode: small gains for smaller SVs

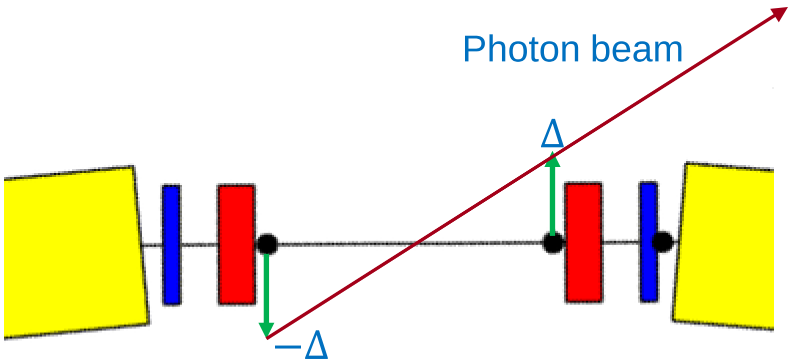


Orbit motion seen by Bergoz BPM in 4kHz mode

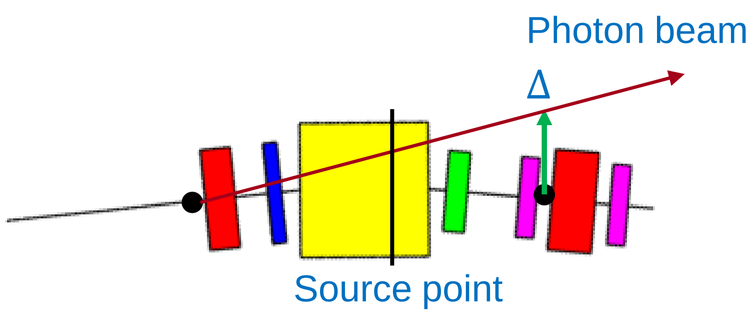


Beamline dynamic steering (BLDS)

- The FOFB Dels allow fast adjustment of the orbit target.
- BLDS adjust the Dels using beamline photon BPMs.



Adjust orbit target for ID beamline



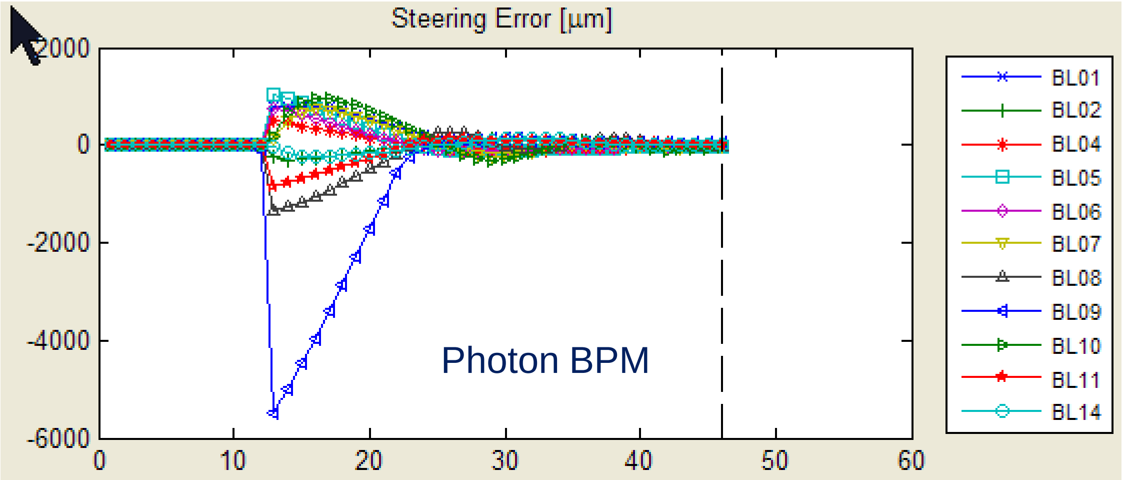
Adjust orbit target for a dipole beamline

- Feedback algorithm
  - Originally BLDS adjust the Dels once every minute to correct photon BPM error (A. Terebilo)
  - In 2010 the BLDS was updated to use a PI feedback loop which update the orbit target every second.

PI gain tune-up

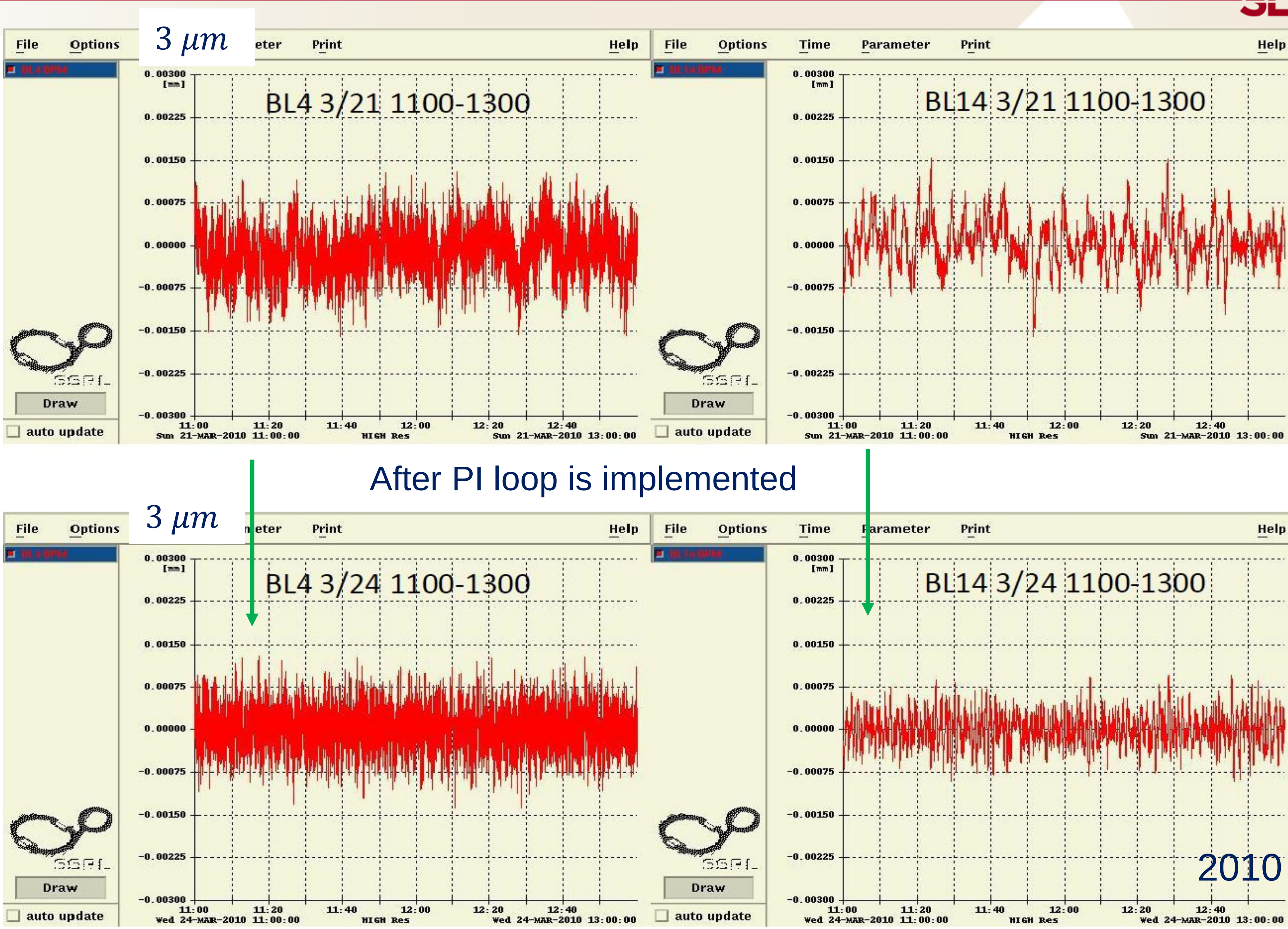
- The PI gains for each beamline is adjusted to optimize performance.
- Step response after tune-up

An initial $100\ \mu m$ eBPM step error for all beamlines



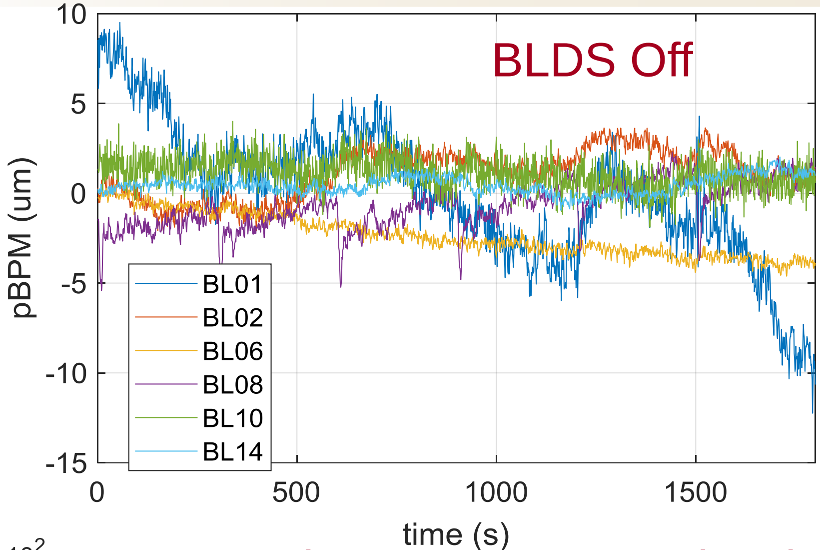
$$K_p = 0.45$$
$$K_i = 0.035$$

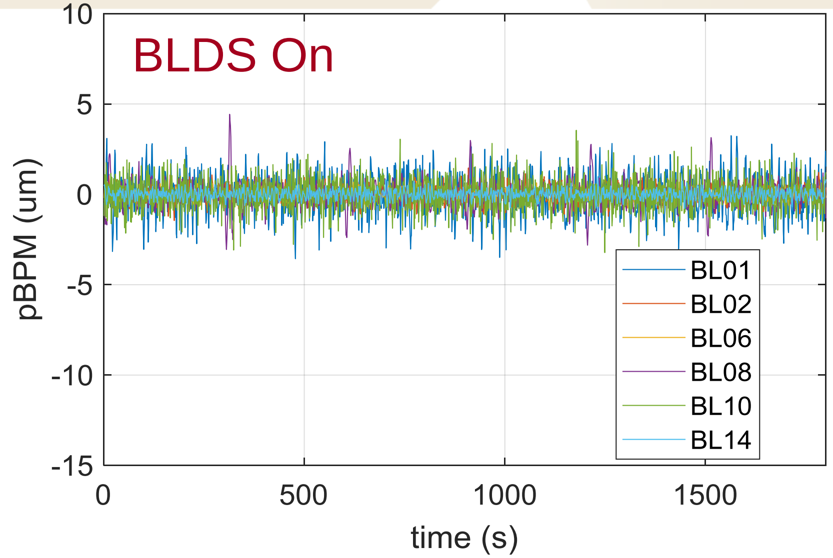
Photon beam stability improvement with BLDS PI loop

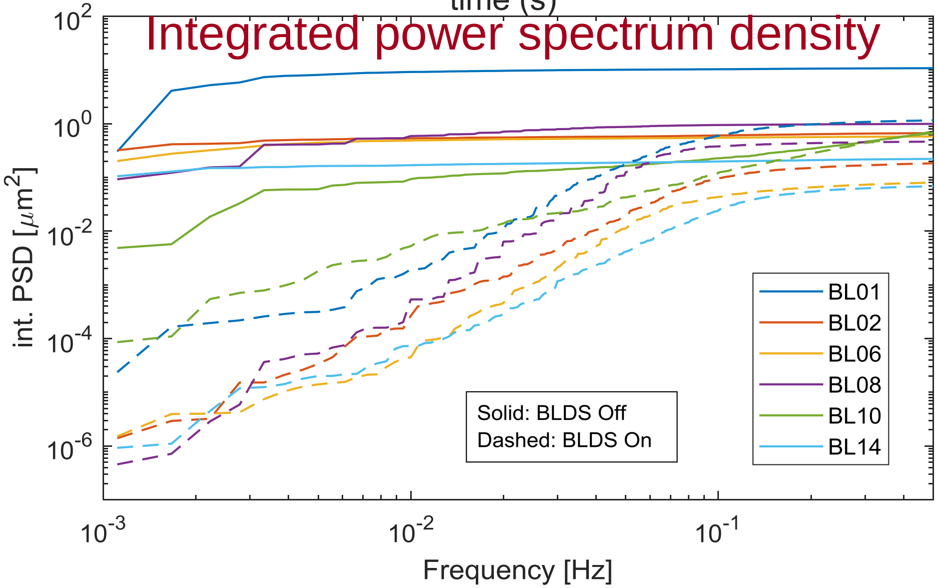


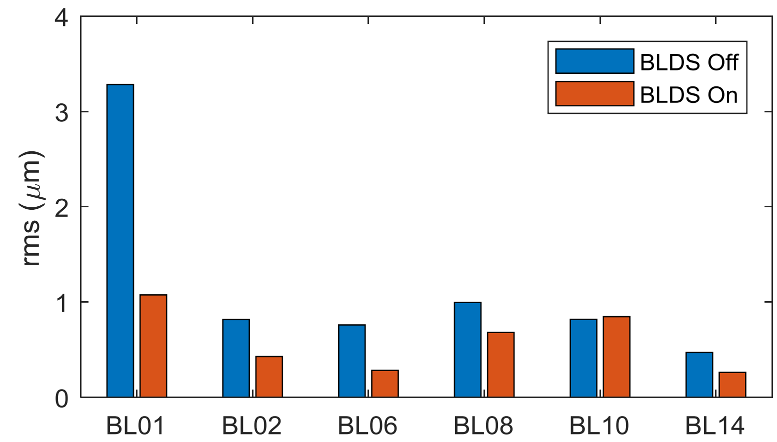
Better flux stability was also reported from beamlines.

Photon beam w/ or w/o BLDS (July 2018 Data)



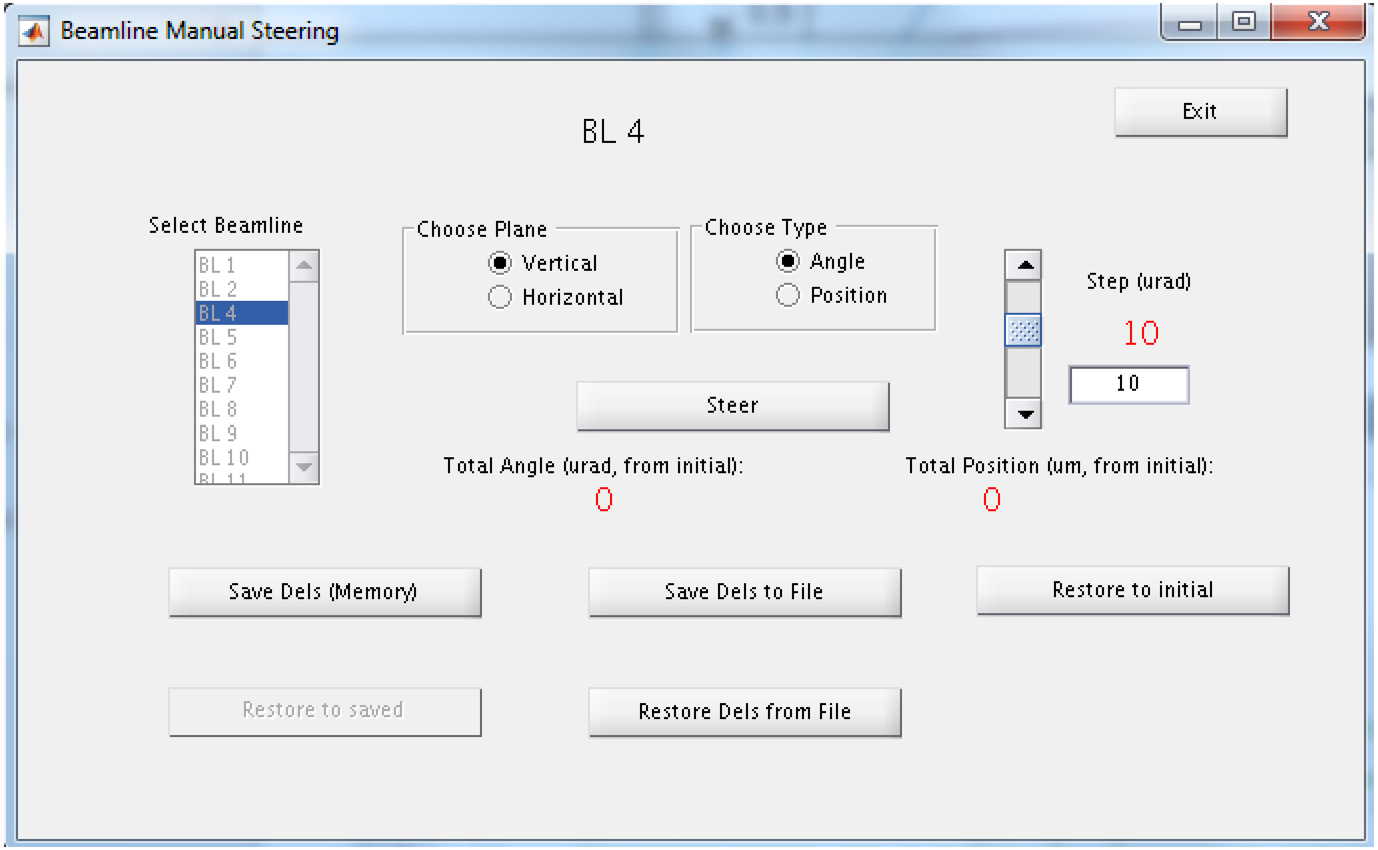






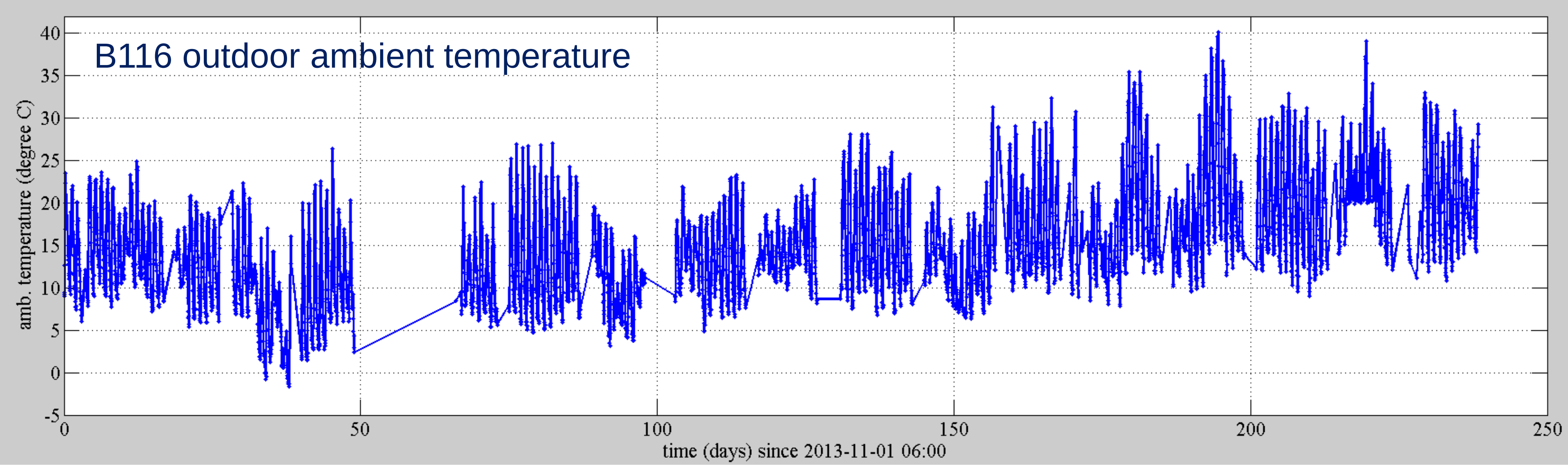
Manual Steering for Beamlines not in BLDS

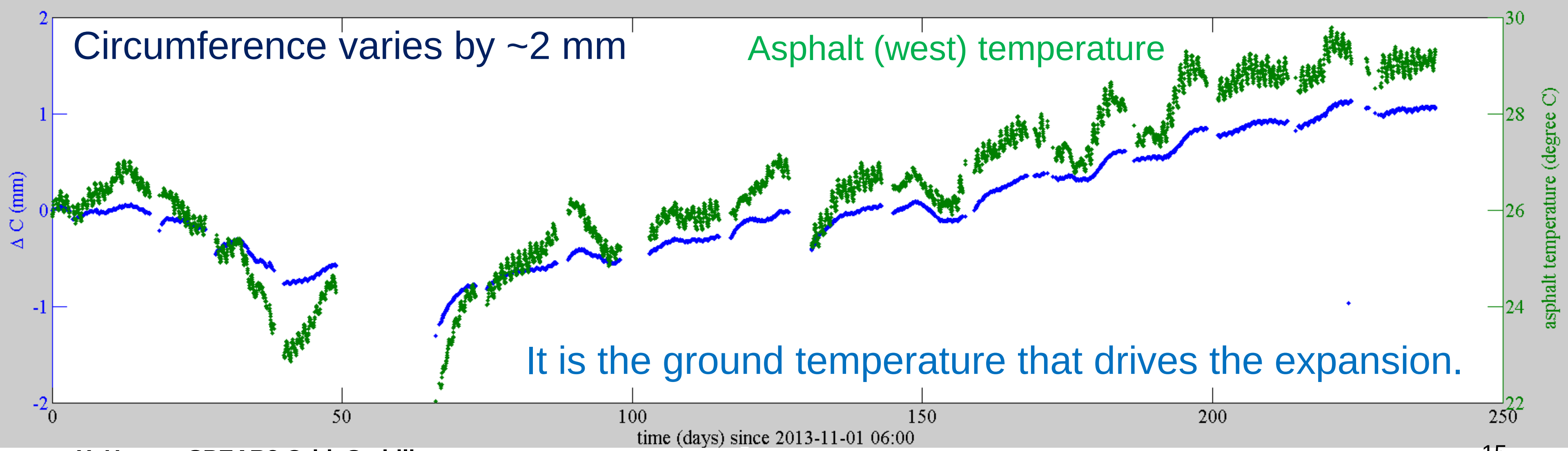
- Manual steering is needed at times at user requests.
- A steering Matlab GUI was developed for the purpose
  - The GUI changes Dels and let FOFB do the steering



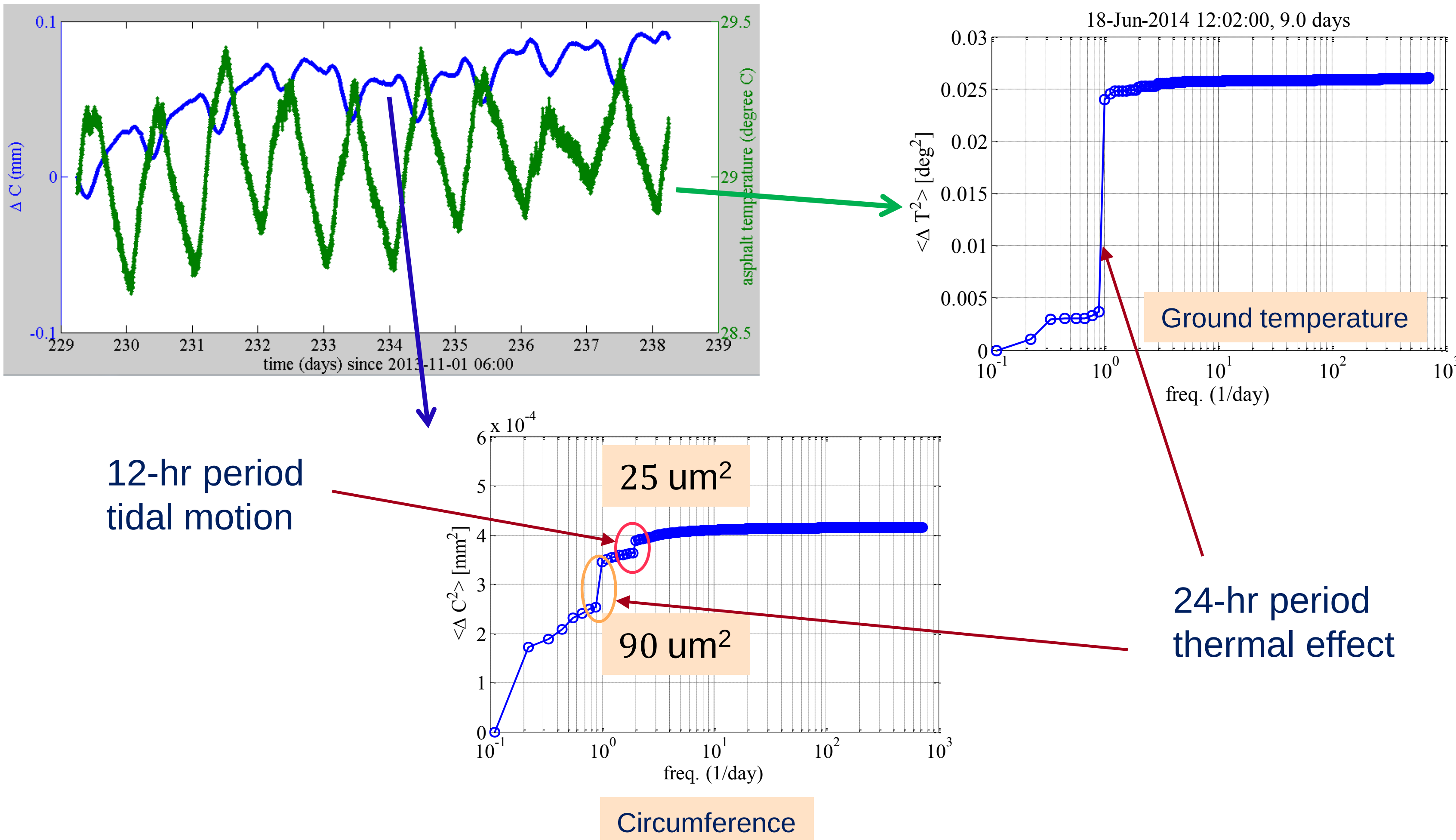
SPEAR3 orbit stability on different time scales

Seasonal ring size variation



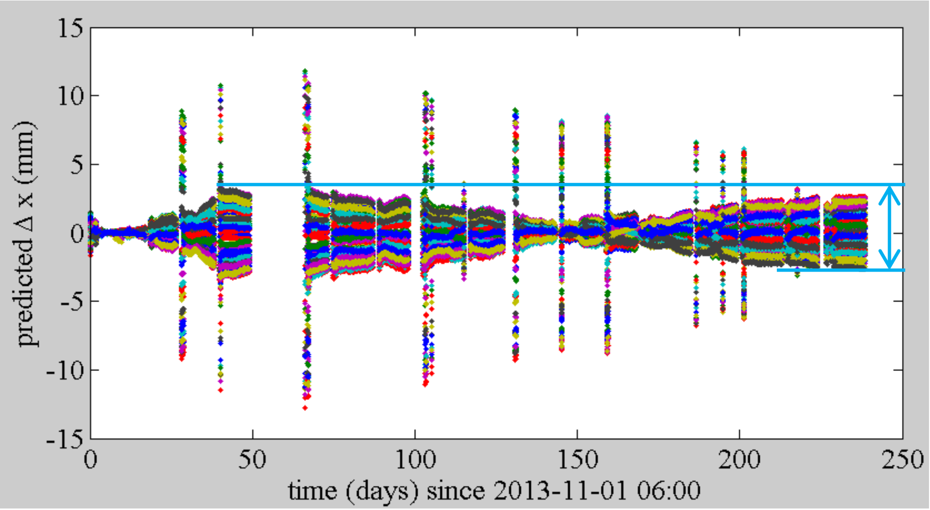


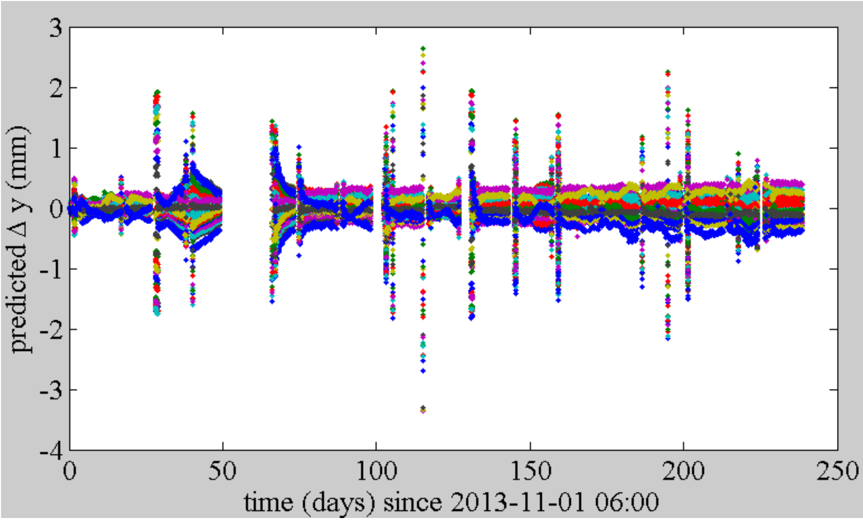
Diurnal variation on ring circumference



Orbit shift corrected by corrector magnets for a year

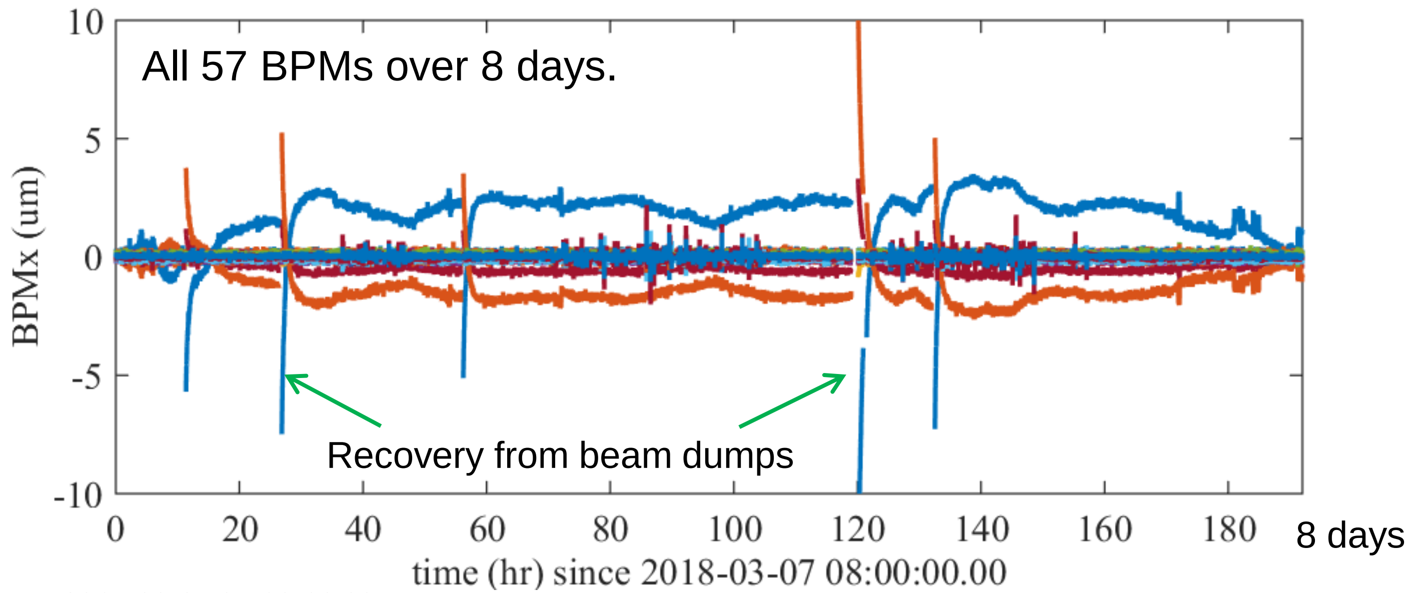
Orbit is corrected toward the target by the Fast Orbit Feedback (FOFB).

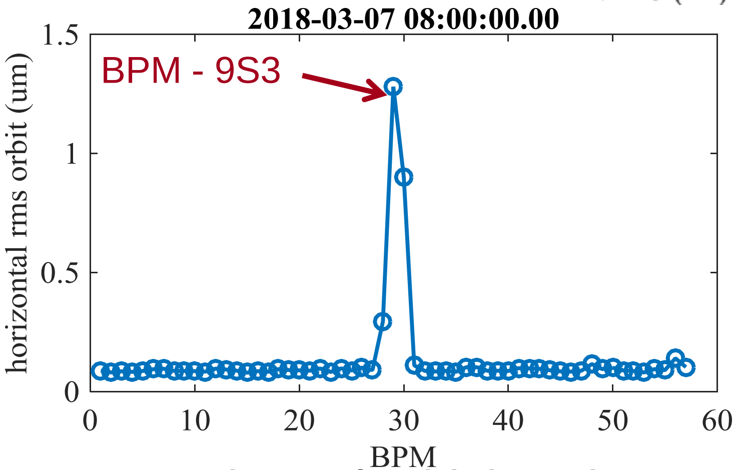


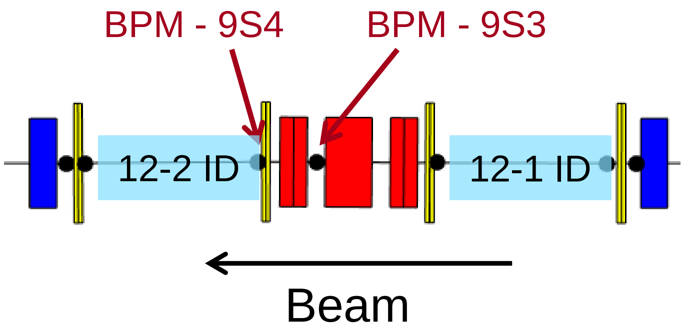


Orbit shift calculated with history data of corrector magnets using orbit response matrix.

Horizontal orbit drift as seen by BPMs over 8 days

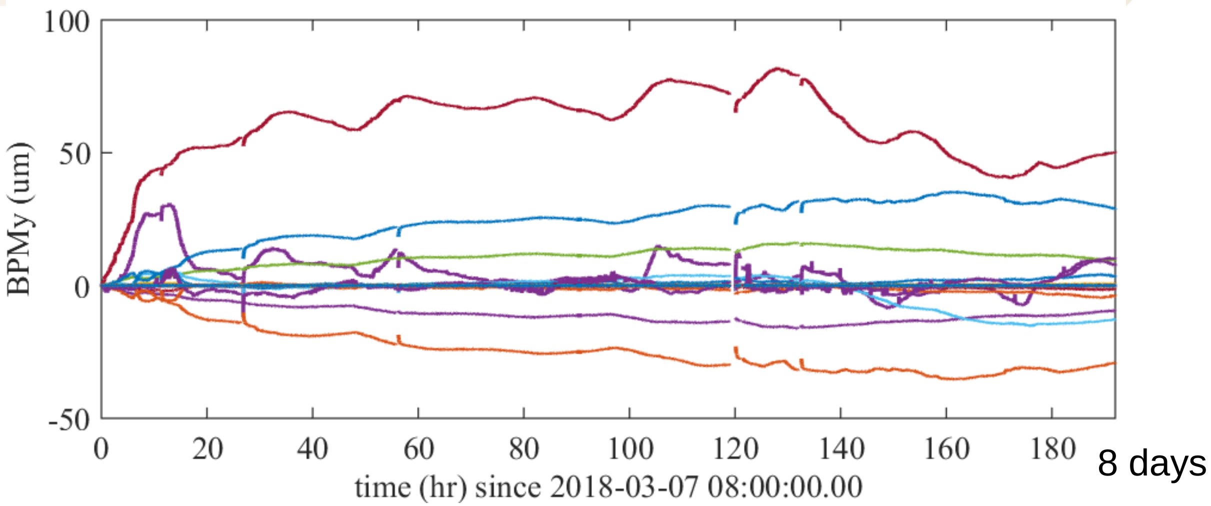


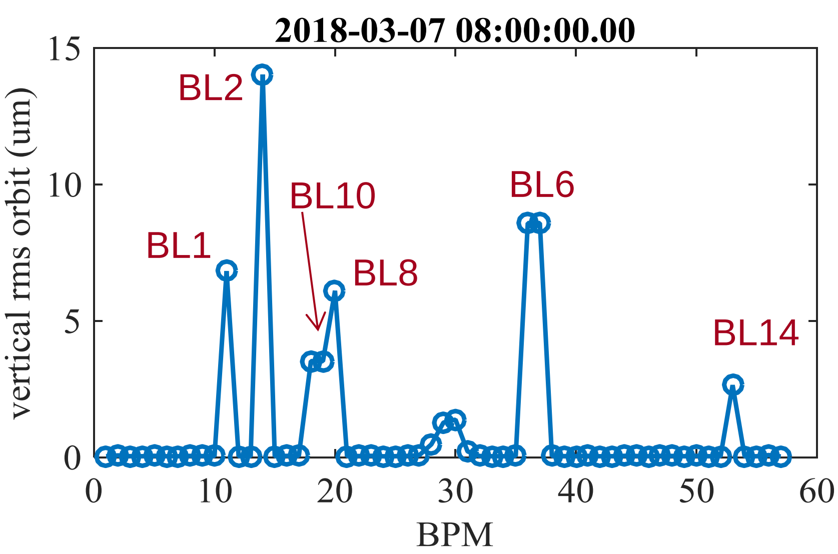




Horizontal orbit is quiet everywhere except between BL 12-1 and 12-2.

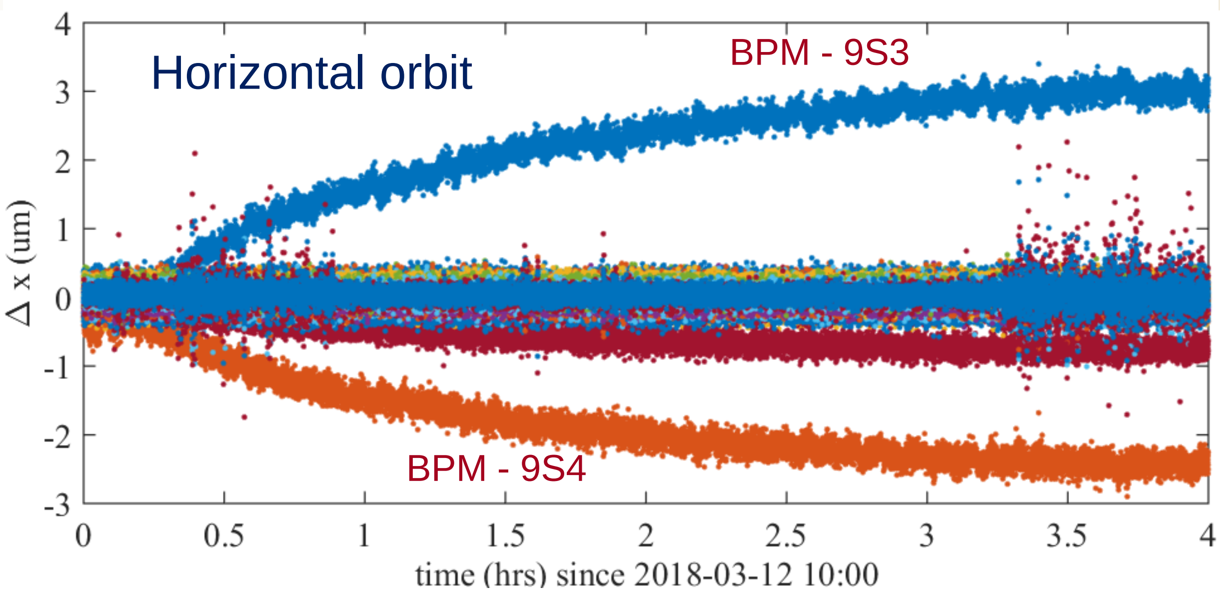
Vertical orbit drift as seen by BPMs over 8 days





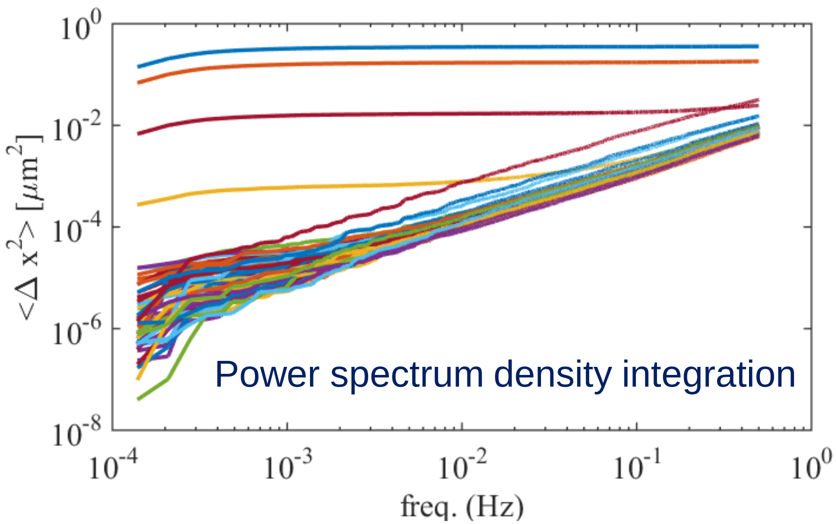
Vertical orbit is quiet except those driven by beam line dynamic steering (BLDS) and at BPM 9S3 and 9S4.

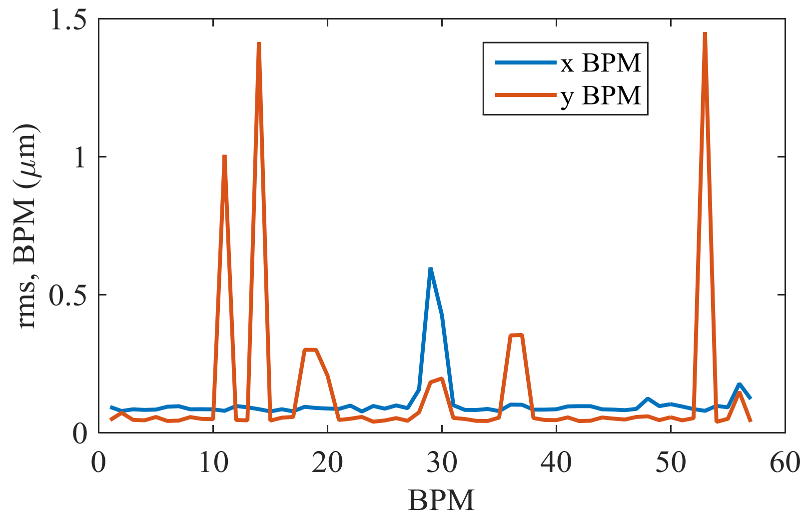
Orbit drift over 4 hrs (high resolution, 1 sec interval)



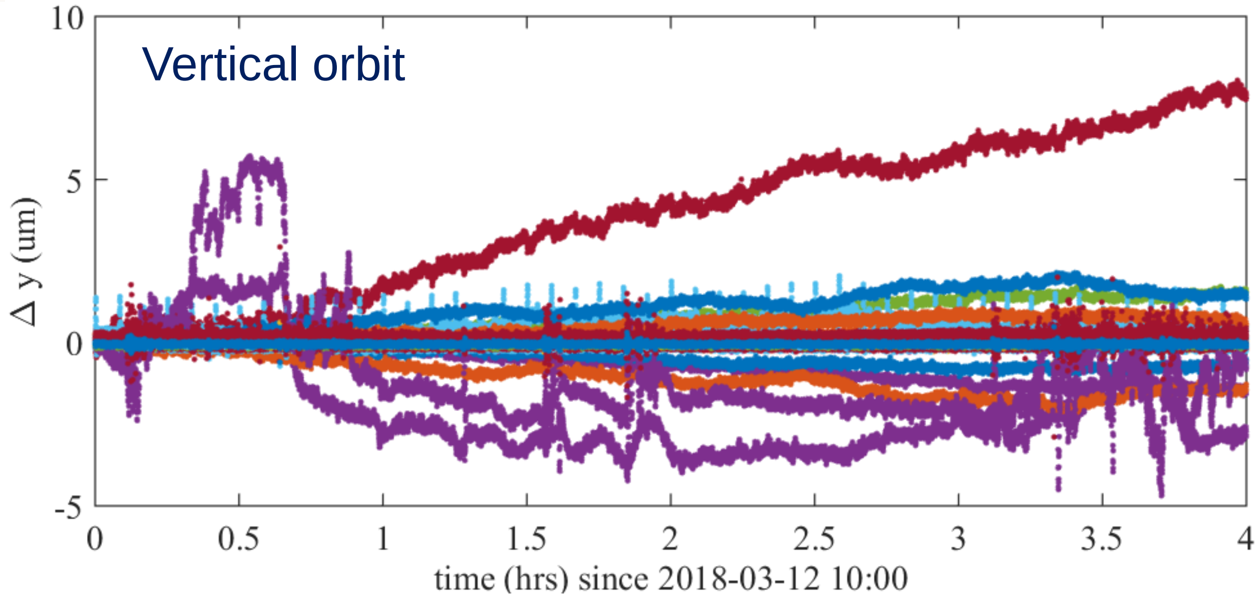
Horizontal orbit is well under control except there is some drift in the 9S area.

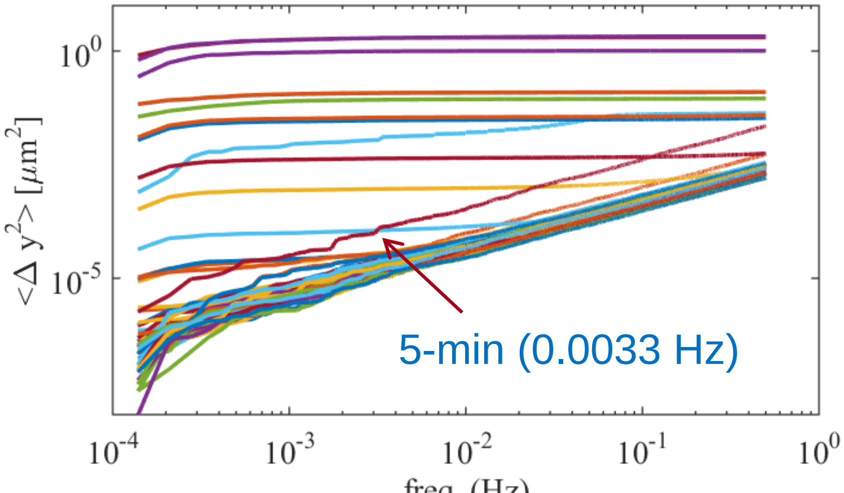
Orbit rms **X = 0.1 um**





Vertical orbit variation over 4 hrs

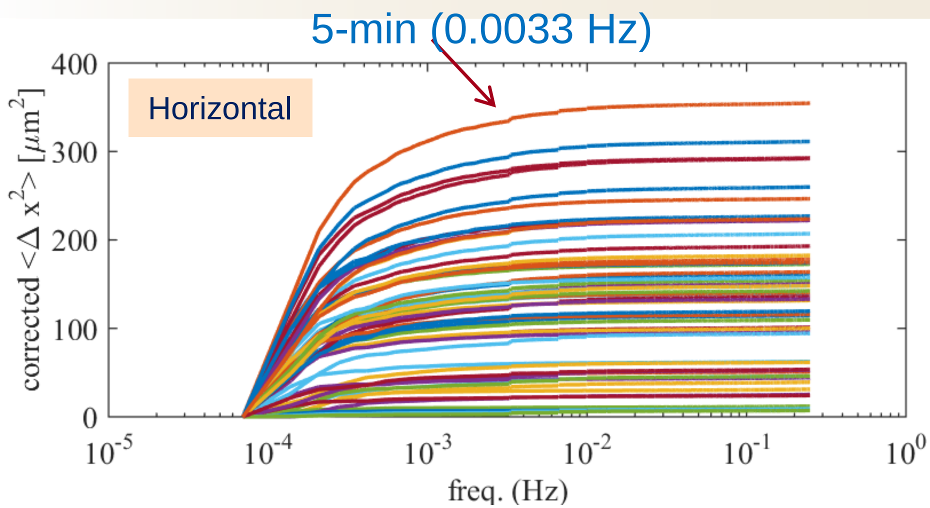


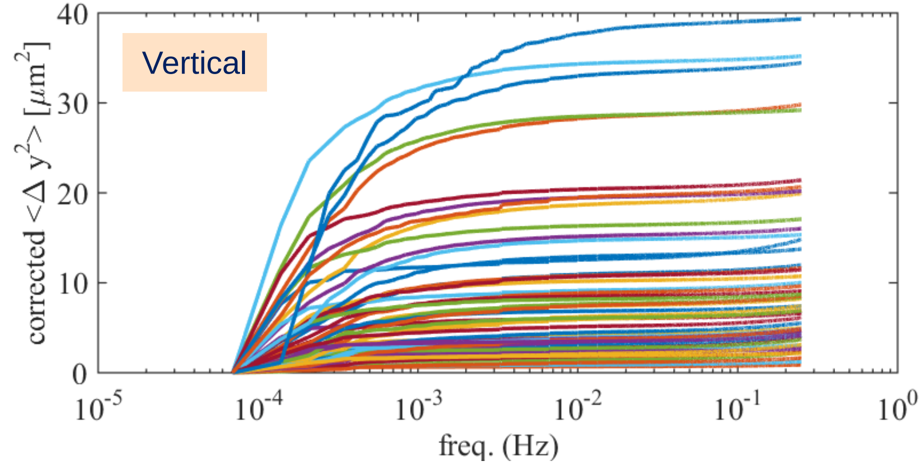


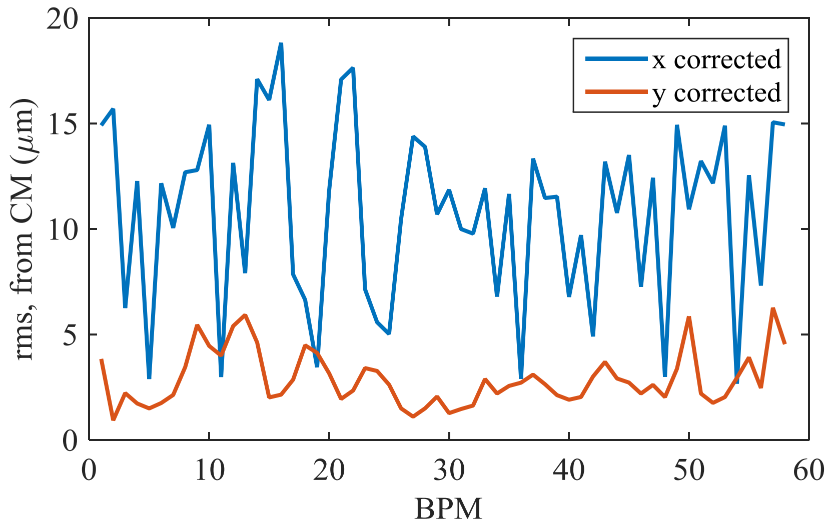
Vertical orbit changes are due to beamline dynamic steering except small drift at 9S.

Orbit rms **Y = 0.05** um at BPMs not affected by BLDS

Orbit motion corrected by FOFB

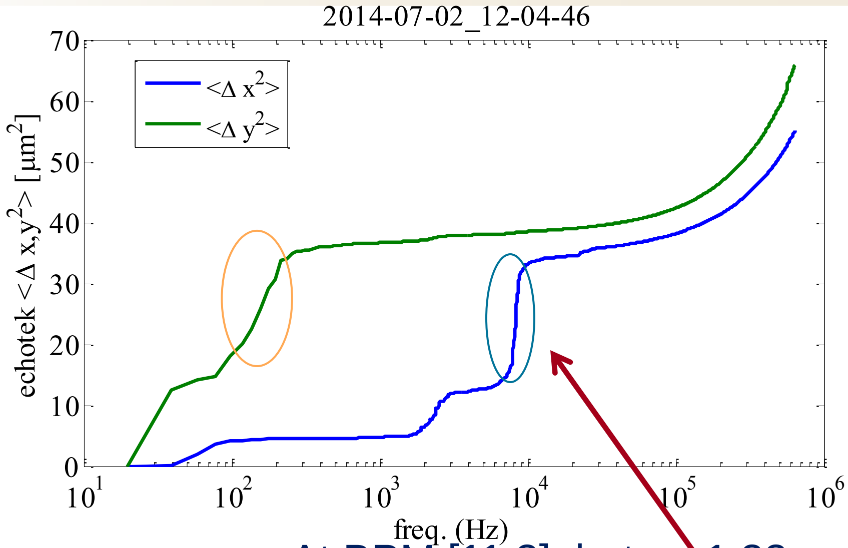


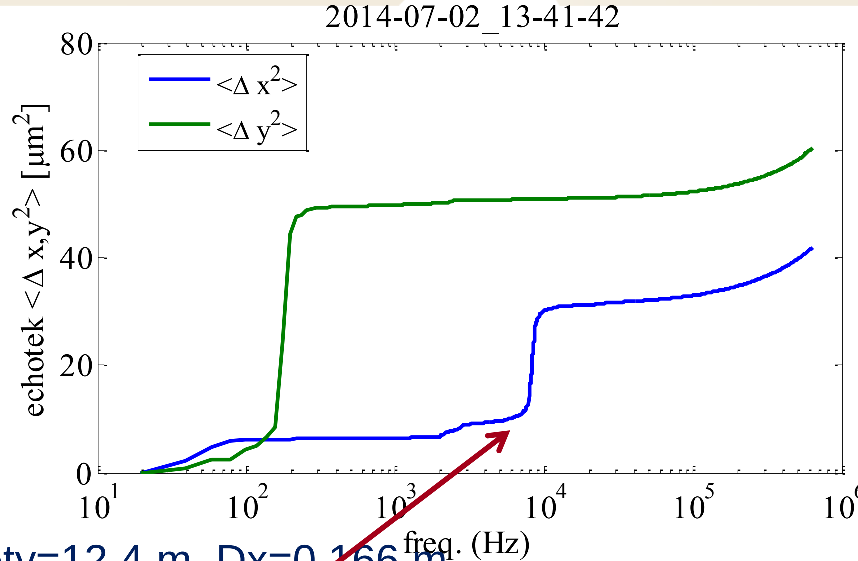




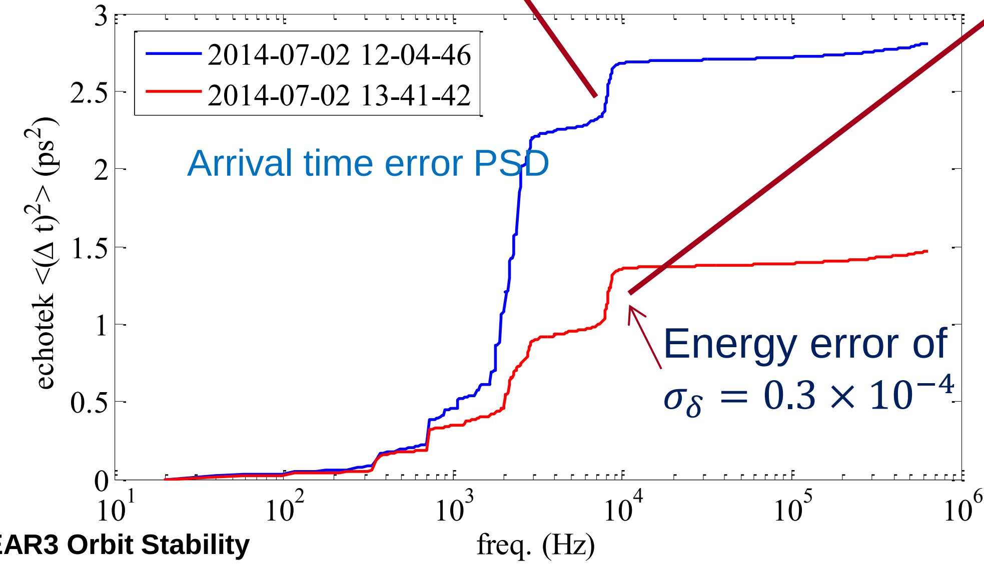
Orbit motion as calculated from history data of corrector magnets (using orbit response matrix)

Turn-by-turn (1.28 MHz) BPM data (Echotek)





At BPM [11,3], betx = 1.33 m, bety=12.4 m, Dx=0.166 m.

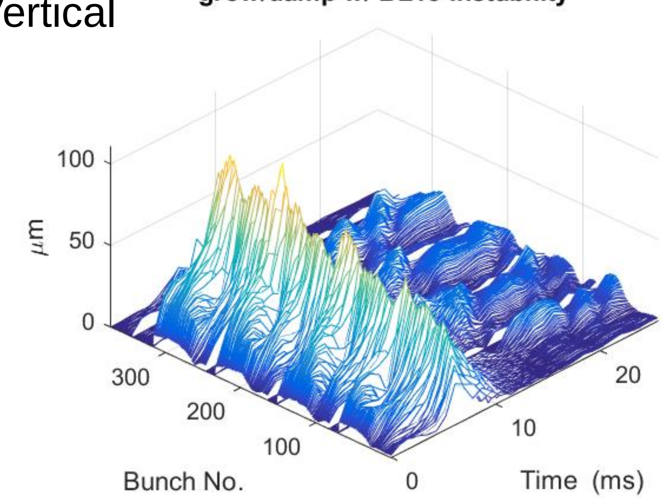


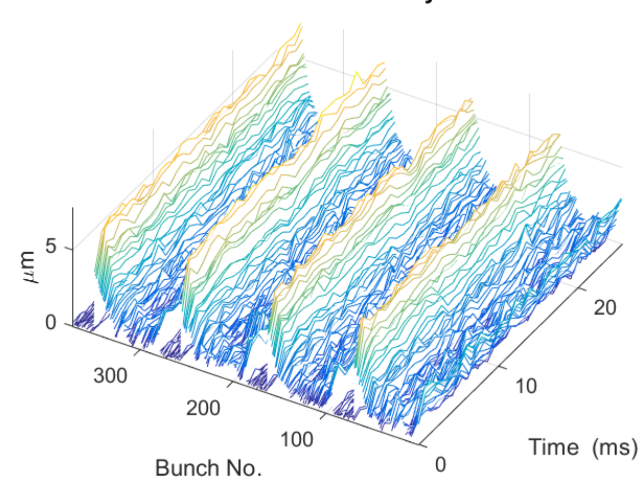
Slow noise on Δt (<3 kHz) does not scale to energy error by the same ratio as synchrotron noise.

$$\frac{\sigma_\delta}{\sigma_t} = \frac{\omega_s}{\alpha}$$

Bunch-by-bunch stability data

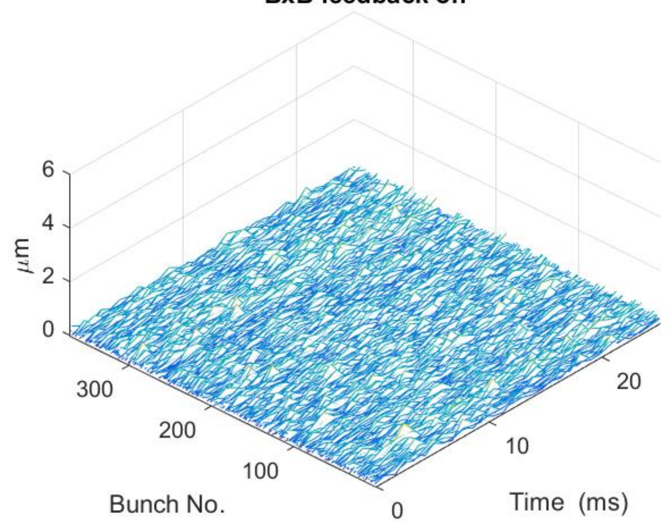
Vertical





K. Tian

In operation, bunch motion is below 1 um



Summary

- Orbit control is at 0.1 um rms at 1 Hz level, except in the 9S area.
- BLDS stabilizes photon beam (measured by pBPM) to below 1 um rms.
  - Vertical eBPM target changes by up to 15 um daily due to BLDS.
- Slow orbit drift (diurnal and seasonal) corrected by the orbit feedback are mostly caused by ground motion that is driven by ground temperature.
  - Seasonal ground temperature varies by 7°C, circumference by 2.2 mm, corrected X drift up to 6-7 mm, Y drift 0.8 mm.
  - Diurnal ground temperature (near surface) varies by ~0.5°C, circumference varies 0.025 mm, corrected X drift up to 0.5 mm, Y drift 0.1 mm.
- Below 200 Hz, the rms orbit noise is about 4 um (x and y) at source points.
  - There is no vertical noise source between 200 Hz and 100 kHz.
  - The horizontal noise from 2 to 10 kHz is 3 um for ID beamlines and 12 um for dipole beamlines.
- With BxB feedback, beam is stable above 1.3 MHz