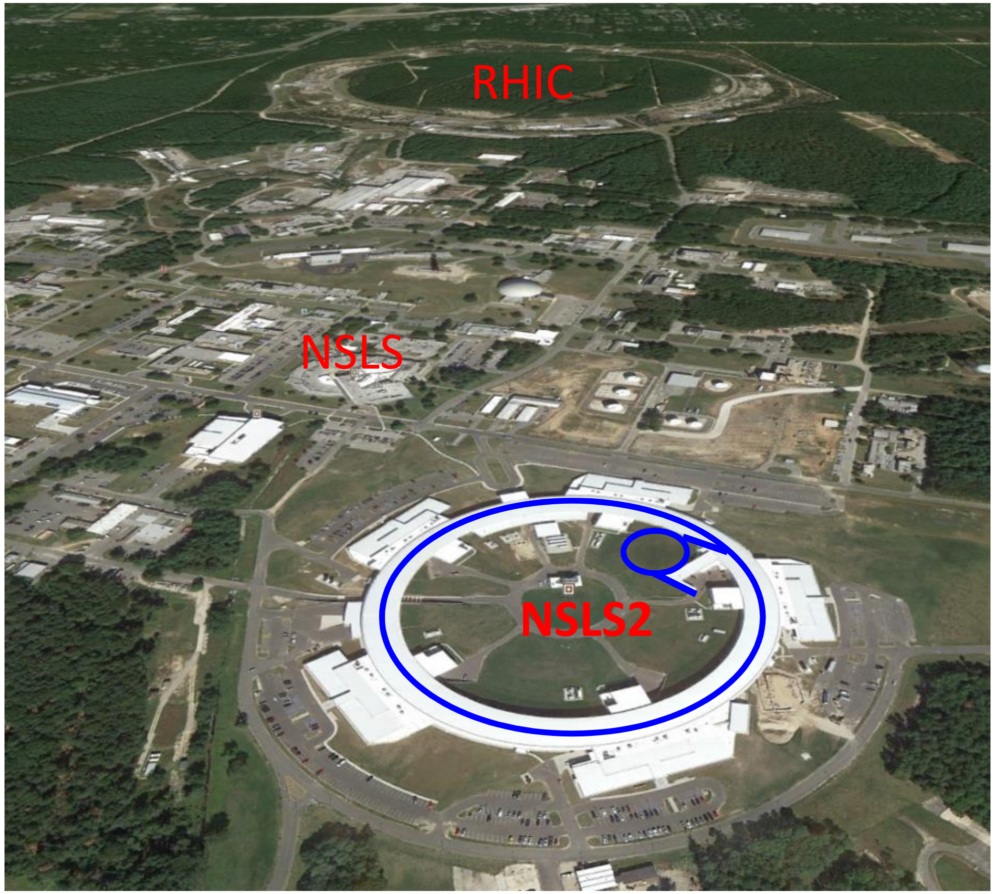
Characterization of NSLS2 Storage Ring Beam Orbit Stability



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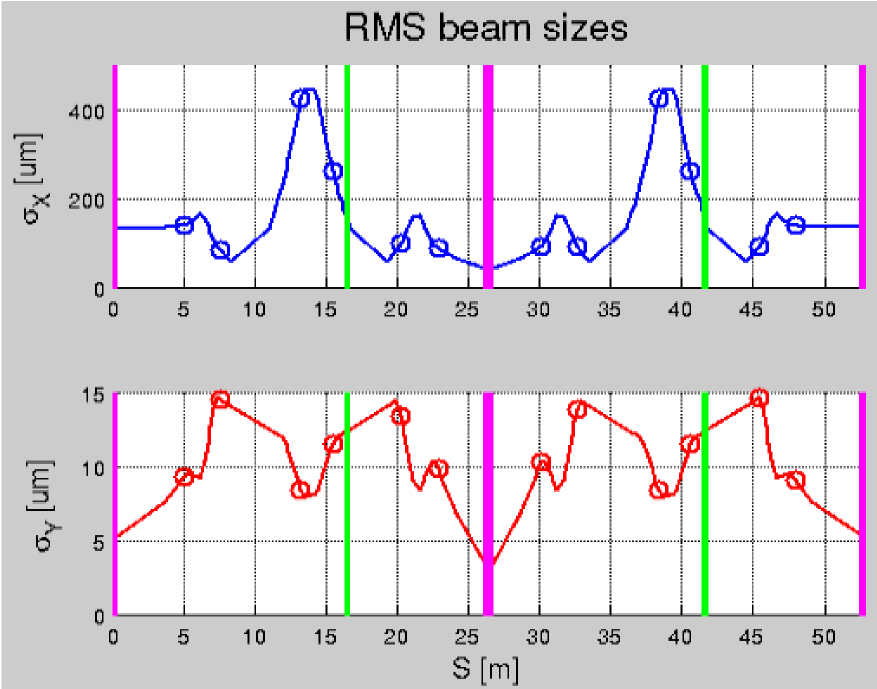
Outline

- NSLS2 BPM system introduction and its performance
  - Types of button BPM and sensitivity
  - BPM electronics data flow
  - Resolution measurement
  - RF attenuator dependency and calibration
  - Current and fill pattern dependency
- Beam orbit spectrum
  - Compare with mechanical vibrations
  - FOFB ON/OFF
  - Compare with xBPM spectrum
- Long term stability
- Summary

NSLS2 storage ring main parameters



Beam sizes in one super period calculated using
ε_x = 0.9 nm.rad, ε_y = 8 pm.rad; $\Delta E/E$ = 0.09%

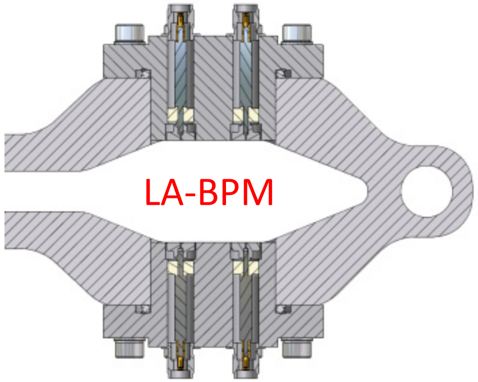
Source point	Long ID	Short ID	3PW	BMB
σ_x [um]	135.0	40.3	153.0	133.1
σ_y [um]	5.2	3.0	12.4	12.5

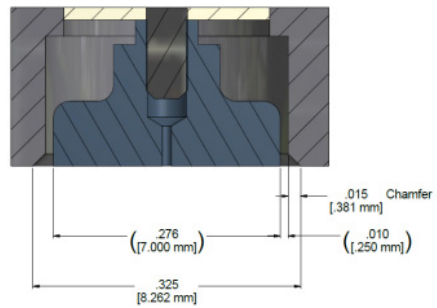
Orbit stability requirements:
< 10% of beam size and divergence

Energy	3.0 GeV
Circumference	792 m
Number of Periods	30 DBA
Length Long Straights	6.6 & 9.3m
Emittance (h,v)	<1nm, 0.008nm
Momentum Compaction	0.00037
Dipole Bend Radius	25m
Energy Loss per Turn	<2MeV
Energy Spread	0.094%
RF Frequency	499.68 MHz
Harmonic Number	1320
RF Bucket Height	>2.5%
RMS Bunch Length	15ps-30ps
Average Current	500mA
Current per Bunch	0.5mA
Charge per Bunch	1.3nC
Touschek Lifetime	>3hrs
Top-Off Injection	1/min

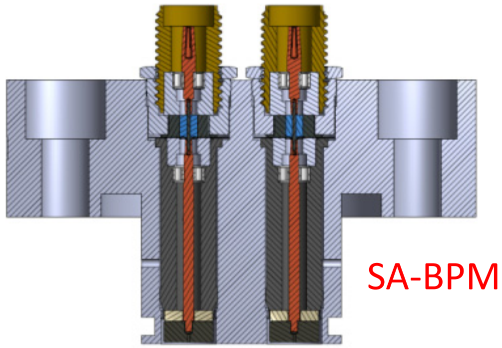
- Types of NSLS2 button BPM:
  - **SR Large Aperture BPM**
  - **SR Large Aperture BPM, 64-deg rotated**
  - **SR Small Aperture BPM - DW, 60-deg rotated**
  - **SR Small Aperture BPM - EPU, 60-deg rotated**
  - **Special injection straight BPMs**

  - LINAC BPM
  - LtB/BtS BPM - round type
  - LtB/BtS BPM - elliptical type
  - Booster BPM - Type-I
  - Booster BPM - Type-II
- Button BPM sensitivity nonlinearity – 1D fitting
- Button BPM sensitivity nonlinearity – 2D fitting

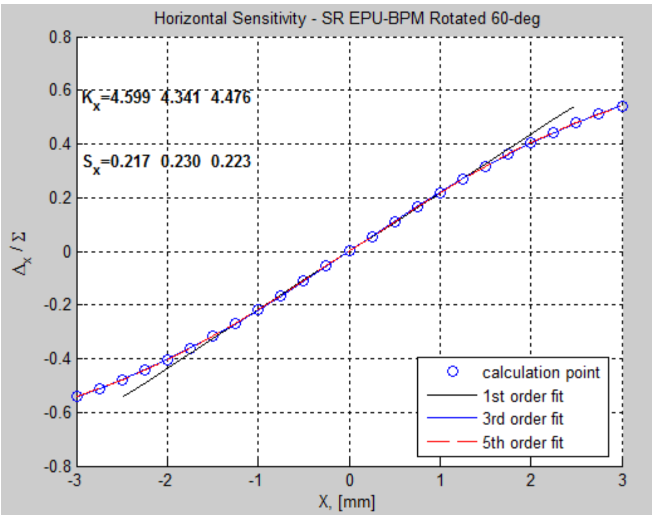


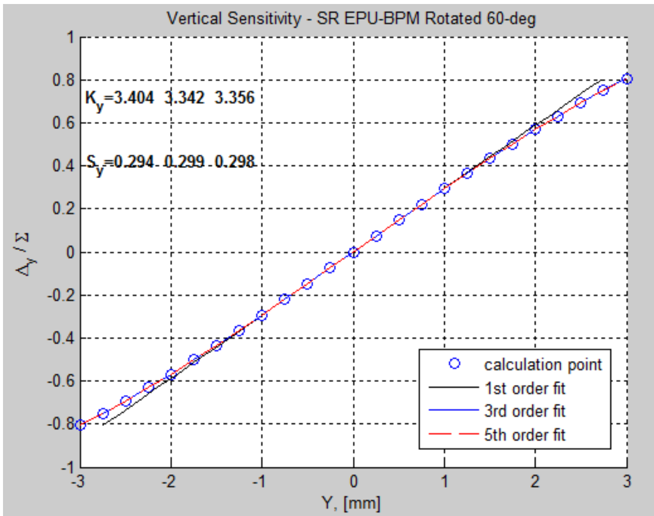


Button diameter – 7mm
Button center distance – 16mm
Gap between button and body – 250μm
Button thickness – 2mm

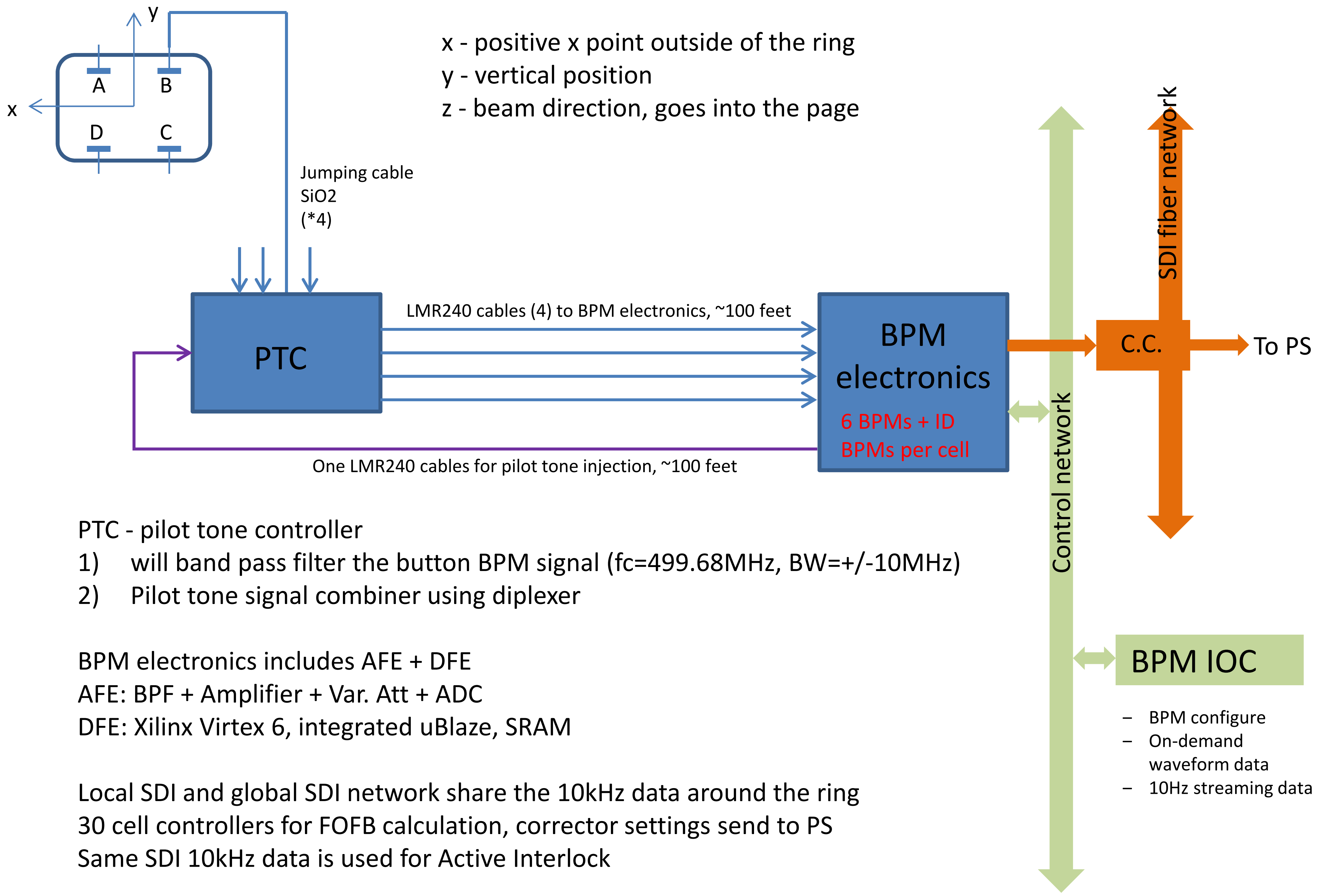


Button diameter = 4.7mm
Button gap = 250μm
Button thickness = 2mm





BPM signal flow



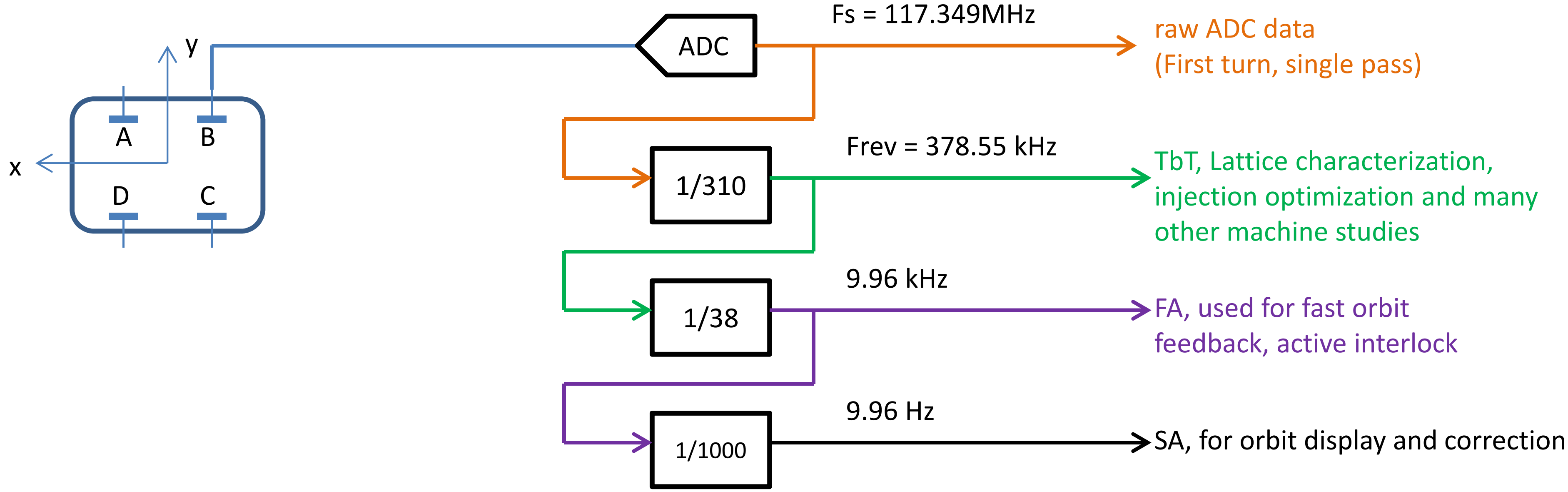
PTC - pilot tone controller

1) will band pass filter the button BPM signal (fc=499.68MHz, BW=+/-10MHz)
2) Pilot tone signal combiner using diplexer

BPM electronics includes AFE + DFE
AFE: BPF + Amplifier + Var. Att + ADC
DFE: Xilinx Virtex 6, integrated uBlaze, SRAM

Local SDI and global SDI network share the 10kHz data around the ring
30 cell controllers for FOFB calculation, corrector settings send to PS
Same SDI 10kHz data is used for Active Interlock

Digital BPM data type (NSLS2 ring)

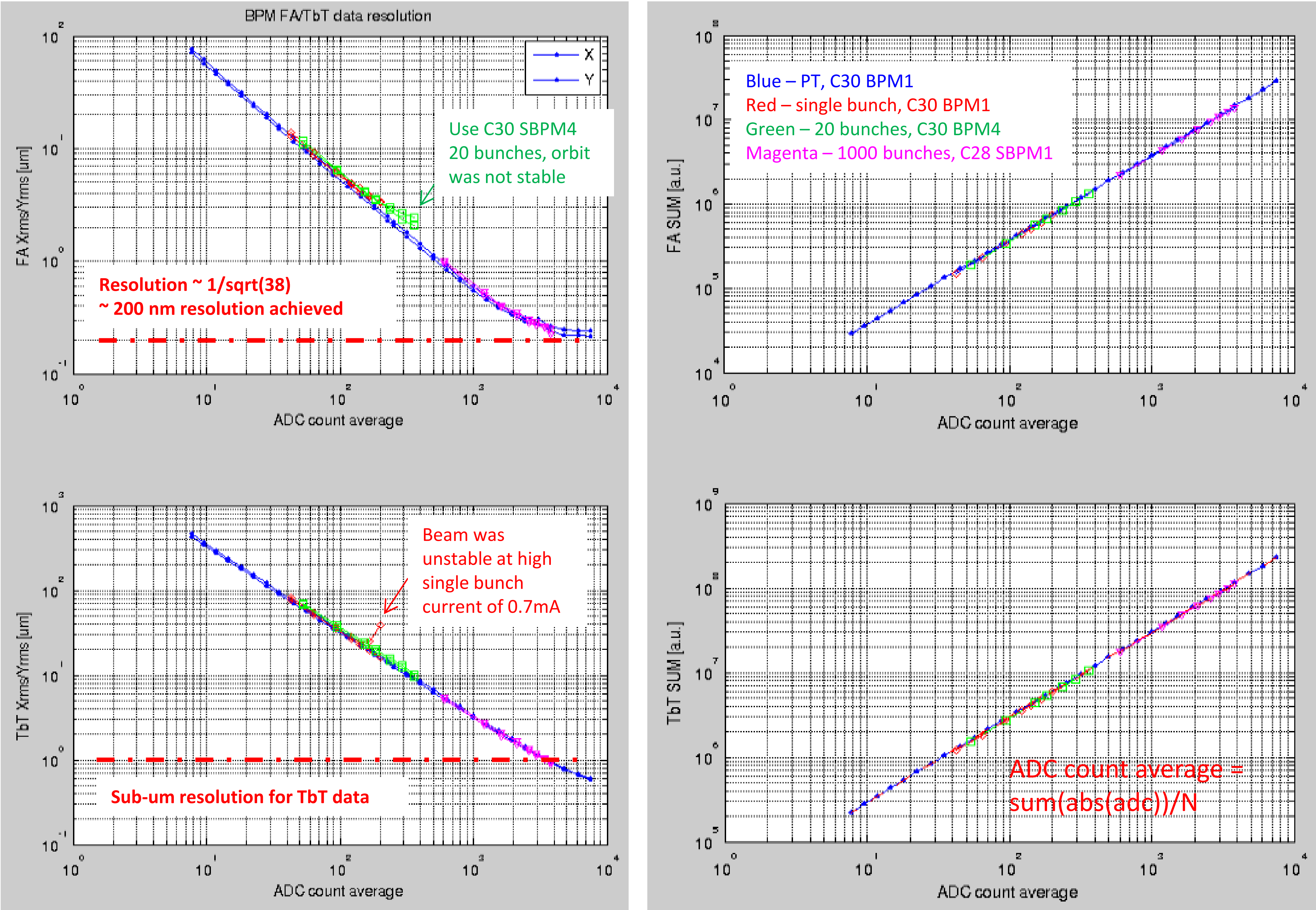


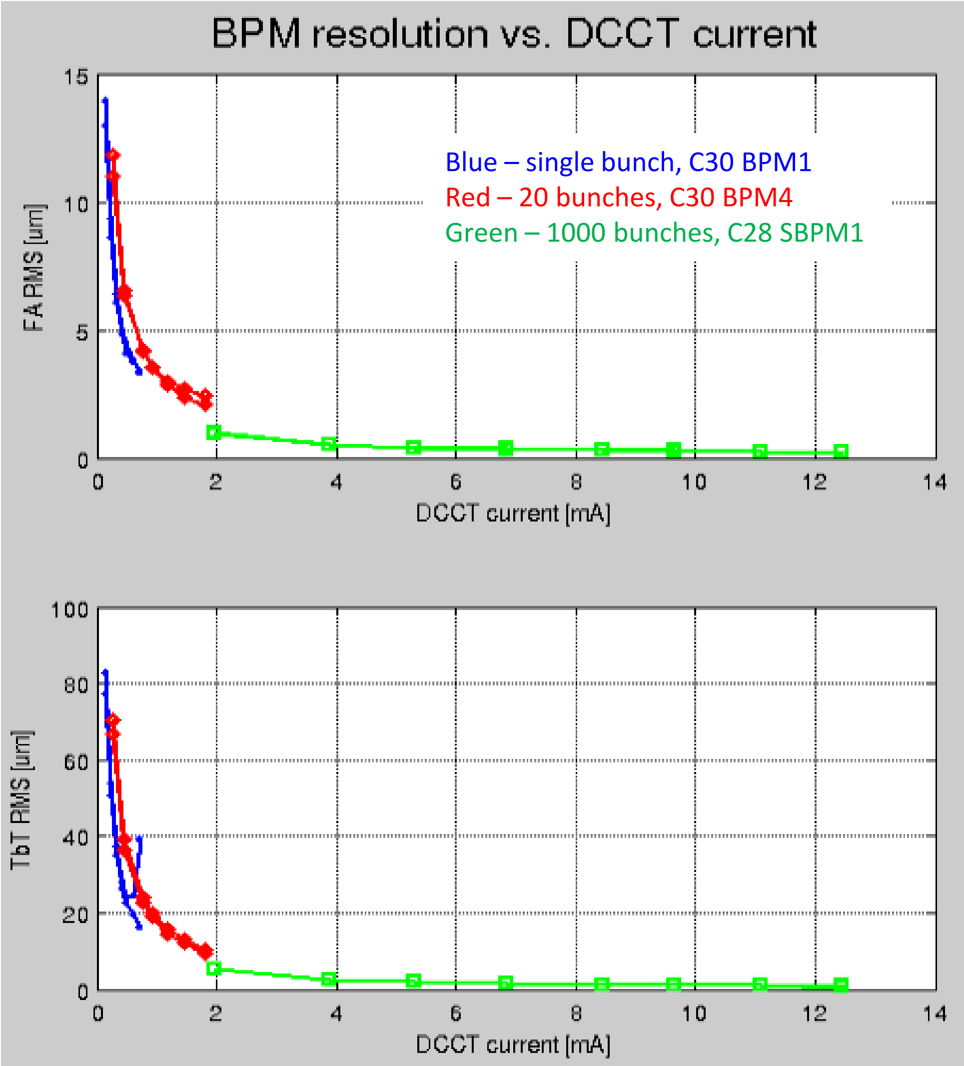
Frf = 499.68 MHz, harNum = 1320, Frev = 378.55kHz

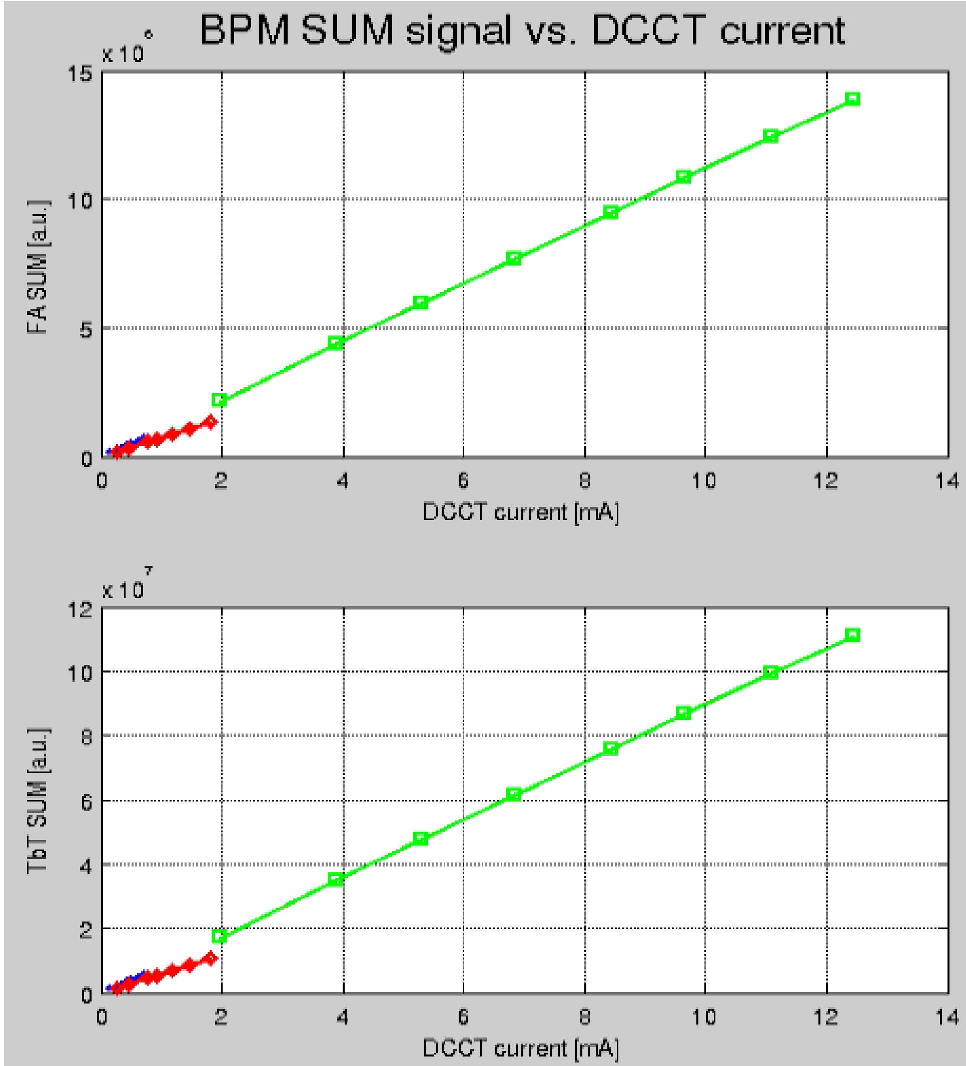
F_adc = 117.349MHz = 310 * Frev

F_if = Frf - 4* F_adc = 1320*Frev - 4*310*Frev = 80* Frev. The 499.68MHz beam signal is in the 9th Nyquist zone with sampling rate of 117.349MHz.

BPM Resolution vs. ADC counts (after BPF)



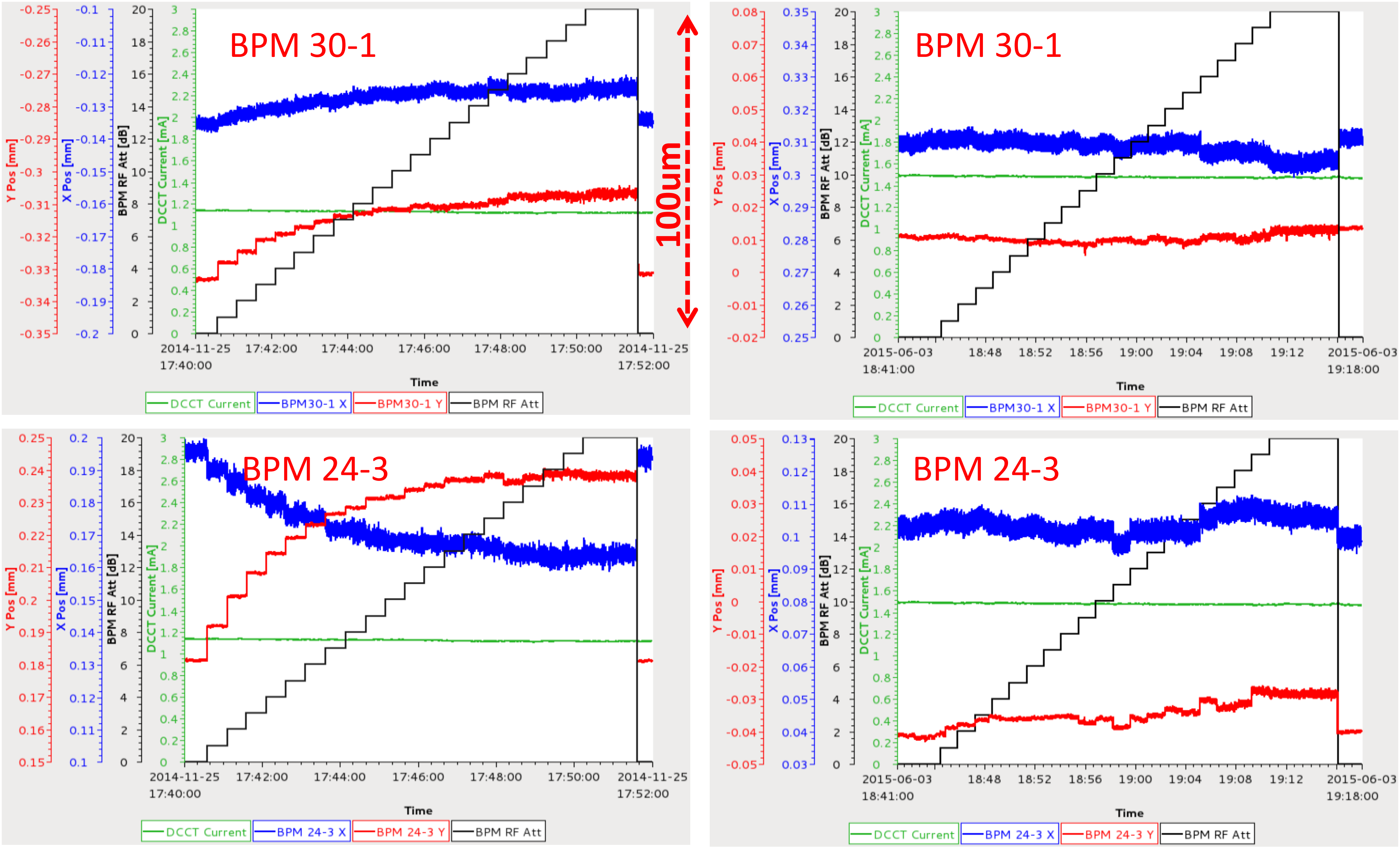




BPM electronics resolution is determined by ADC average counts. It depends on beam current, button sensitivity, attenuator settings etc.

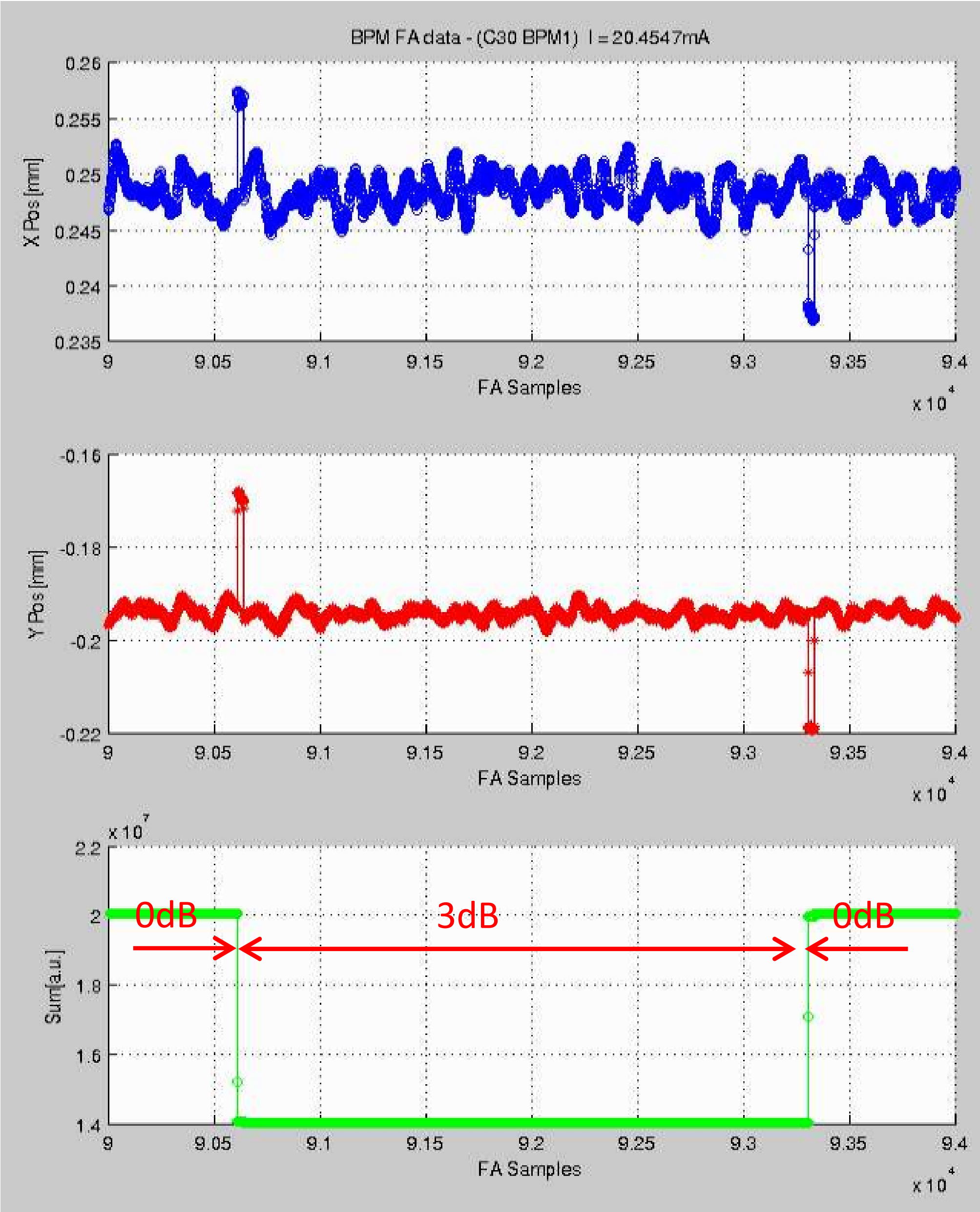
BPM Sum signal could be useful for total current/lifetime measurement. More studies needed as SUM signal may depends on bunch length, fill pattern, beam position, RF attenuator settings etc.

Old LUT   Beam based LUT



With the new static gain calibration LUT, most of the BPMs has RF attenuator dependency less than 10um, while attenuator varied from 0 to 20dB in 1 dB steps. Note that the LUT was generated in Nov 2014 and it's still working in months, with different current and fill pattern.

Glitches while change the BPM attenuator settings

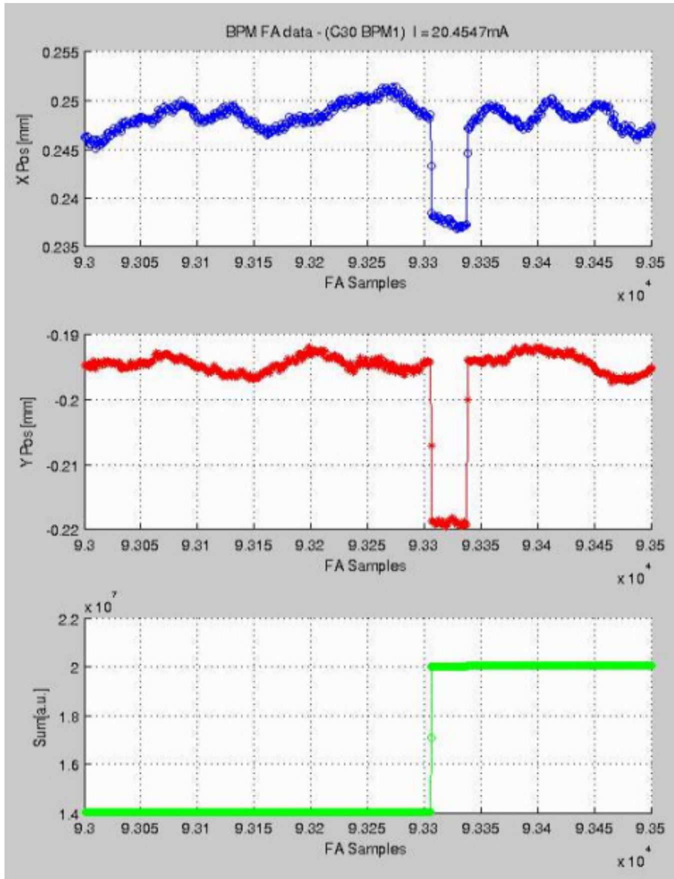


First observed on BPM TbT data, verified with FA data

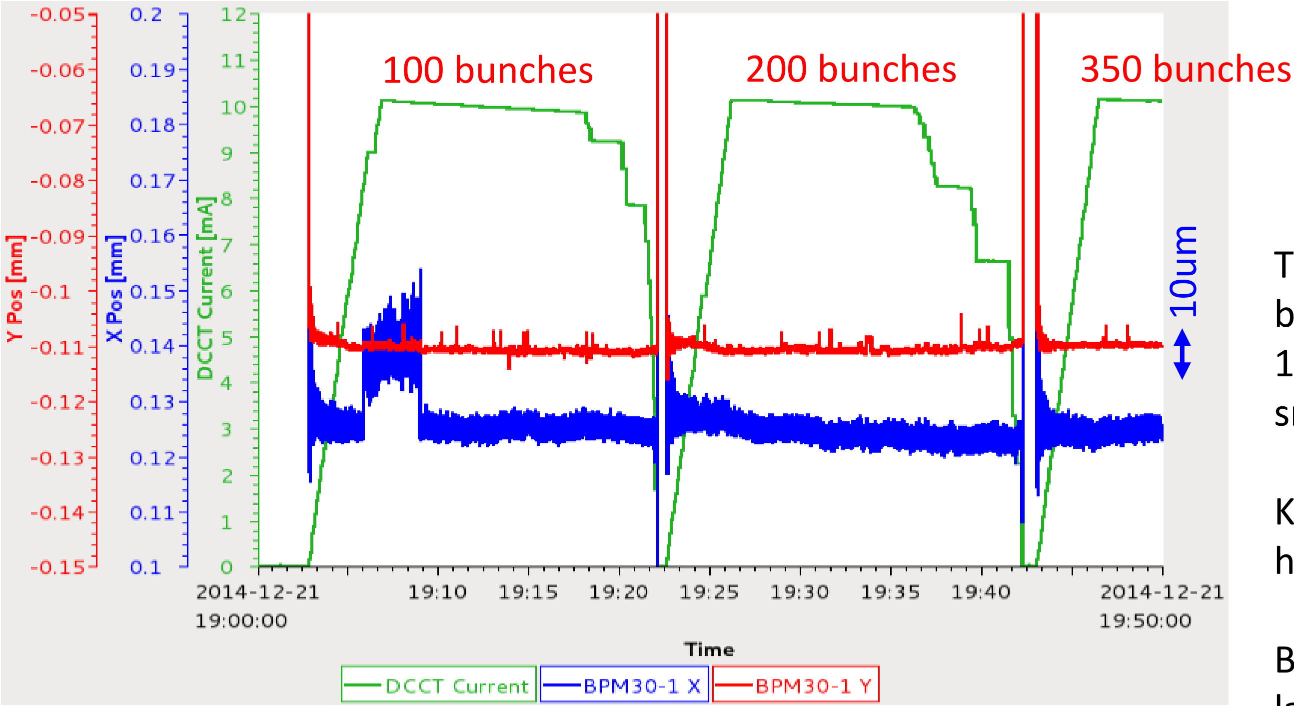
Vary Att 0 to 3 dB during the period. It's clear that when Att was changed, there was a glitch on FA position readings. The glitch last for ~32 FA samples.

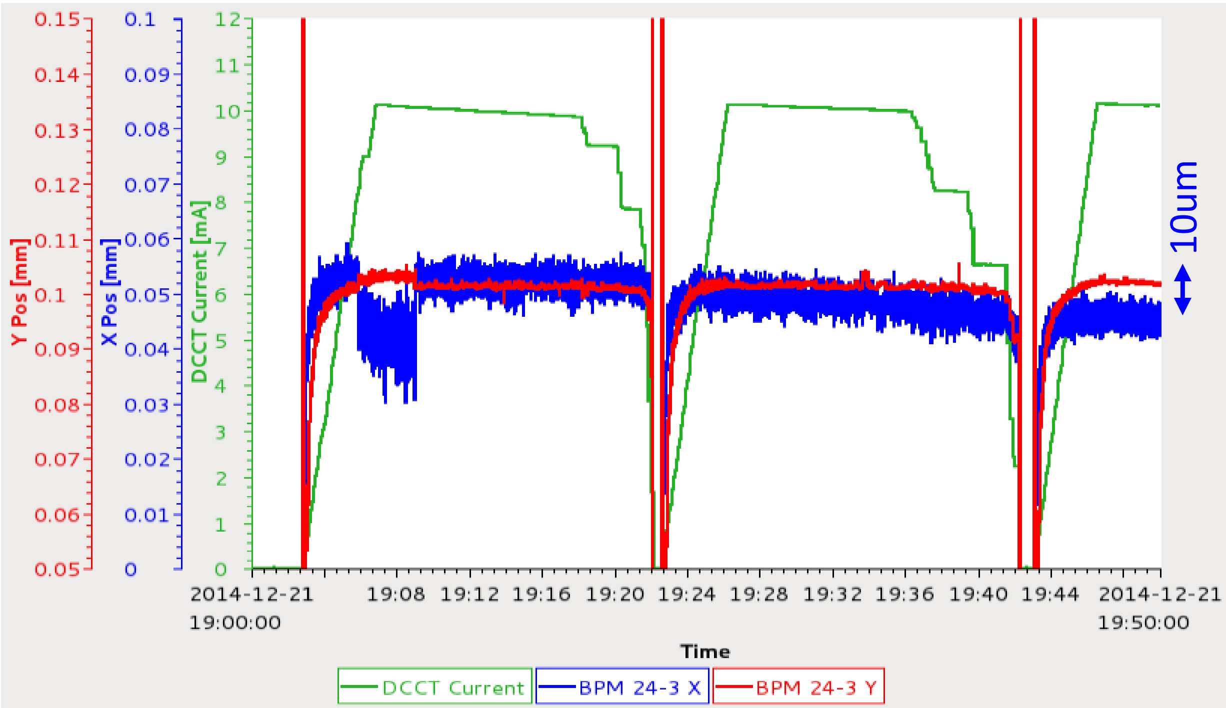
Note the position reading is not changing at 0dB and 3dB, which is because of good RF attenuator calibration.

Turn AGC OFF for user operation, especially when FOFB turned ON



Current and Fill Pattern Dependency



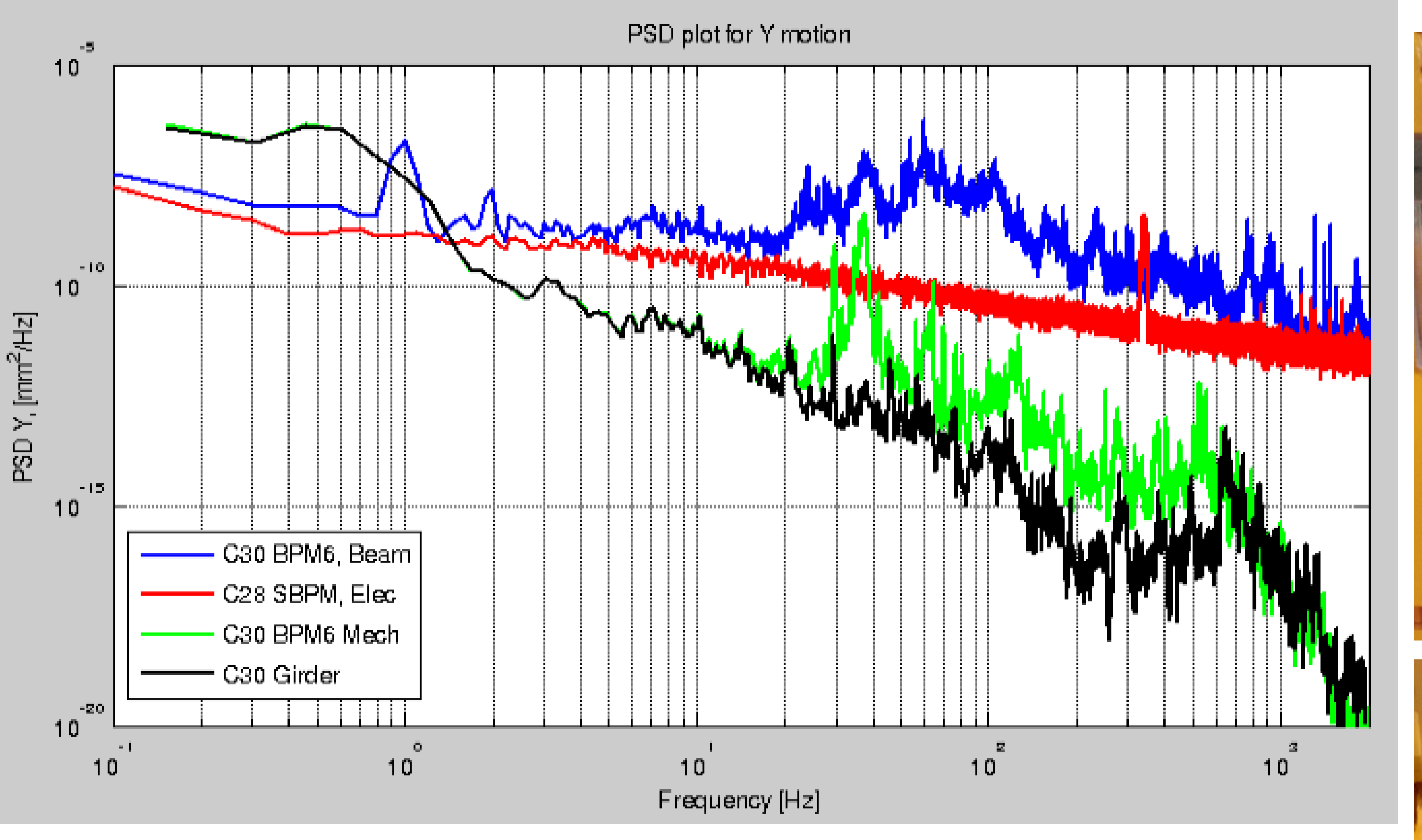


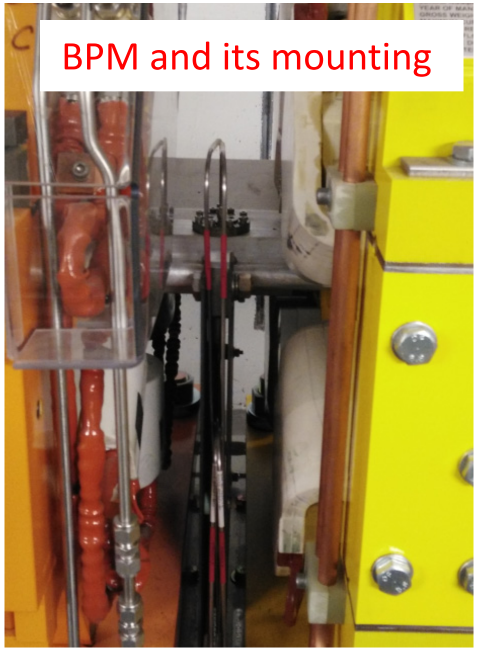
Three different fills to the same total beam current of 10mA distributed in 100, 200 and 350 bunches. Pretty small fill pattern dependency.

Knock out the bunches in steps to have different fill patterns.

BPMs near RF cavity section see larger current dependency, due to leaked noises at Frf. The issue is dominant for single bunch studies when Ib < 0.2mA. Typically not a problem when the beam current is high.

Beam motion spectrum together with mechanical vibrations

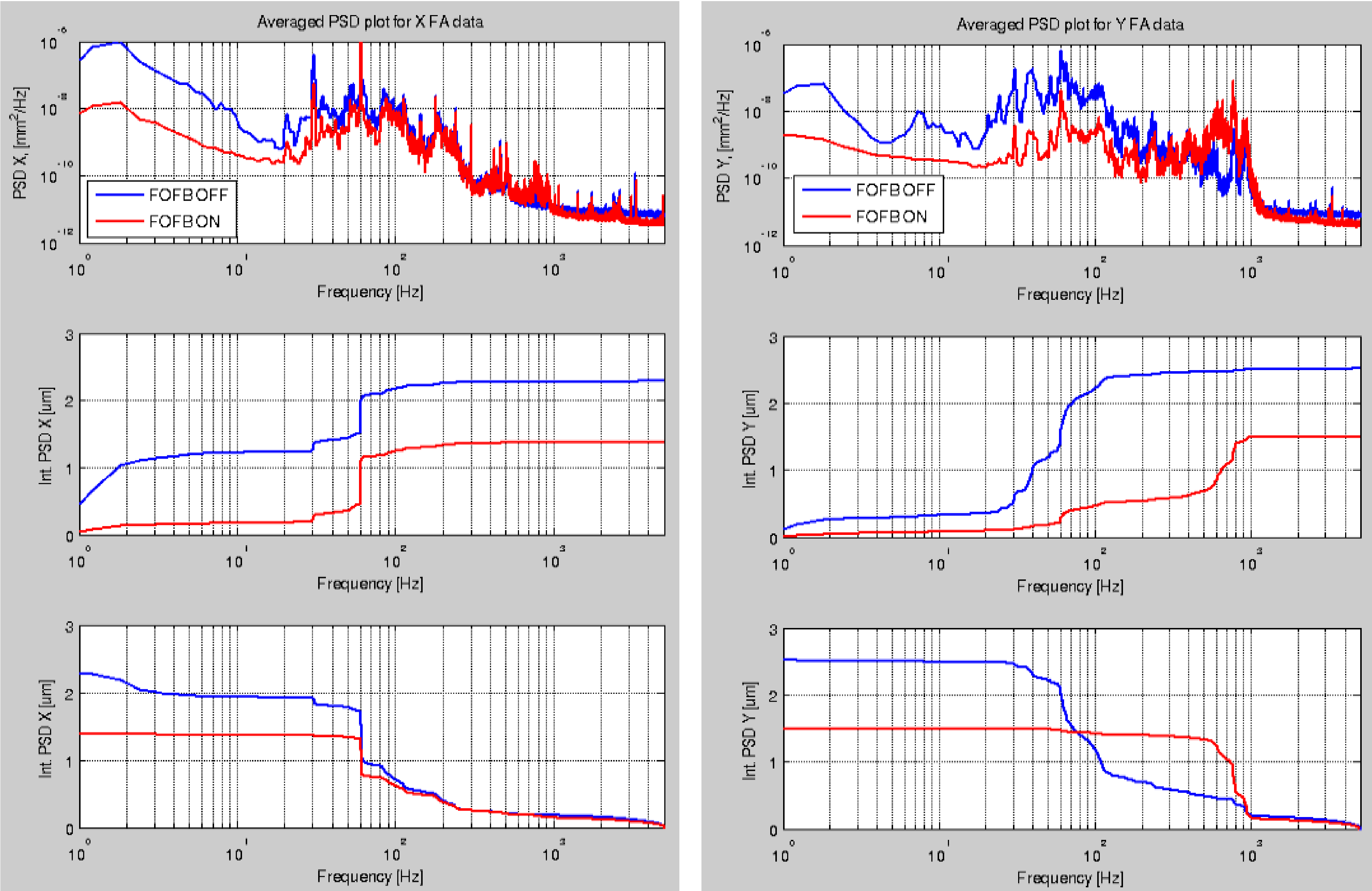




Geophone setup inside the tunnel to collect vibration data for two weeks, with beam.
Black – C30 Girder 6
Green – C30 BPM 6, sensor mounted on chamber surface near the BPM

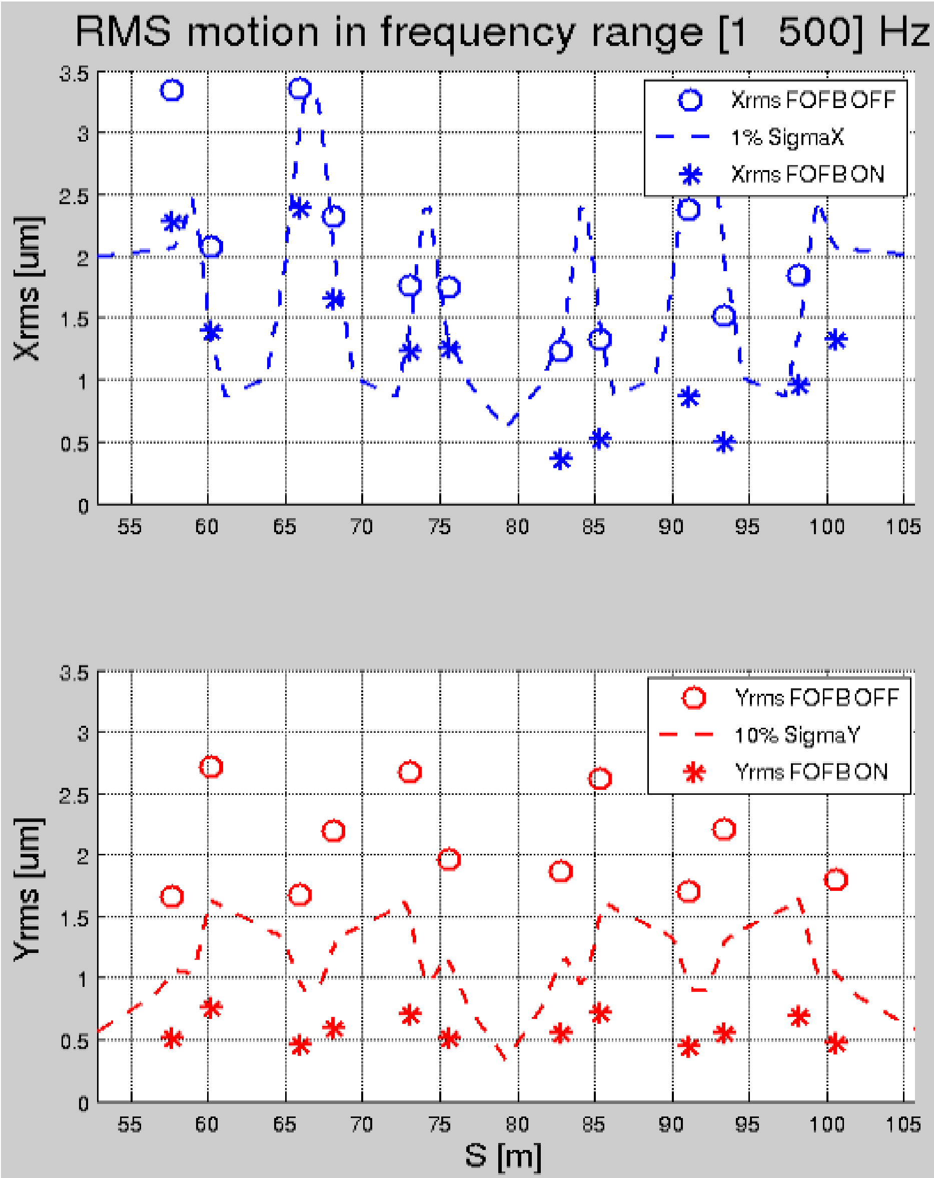
BPM FA data collected during beamline commissioning (4.6mA, multi-bunch fill)
Blue – C30 BPM6
Red – C28 SBPM1 (combiner/splitter)

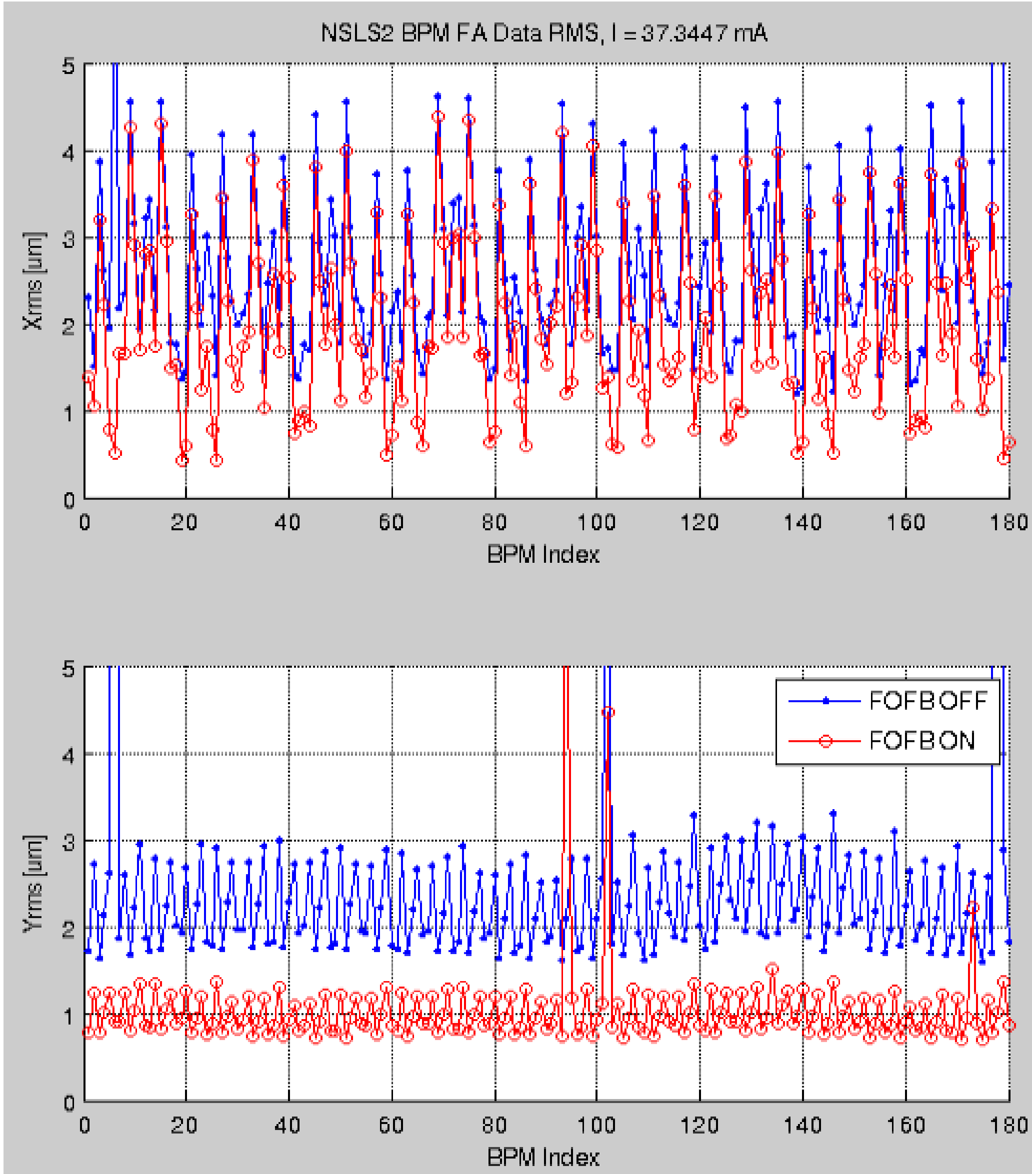
Beam spectrum with FOFB ON/OFF



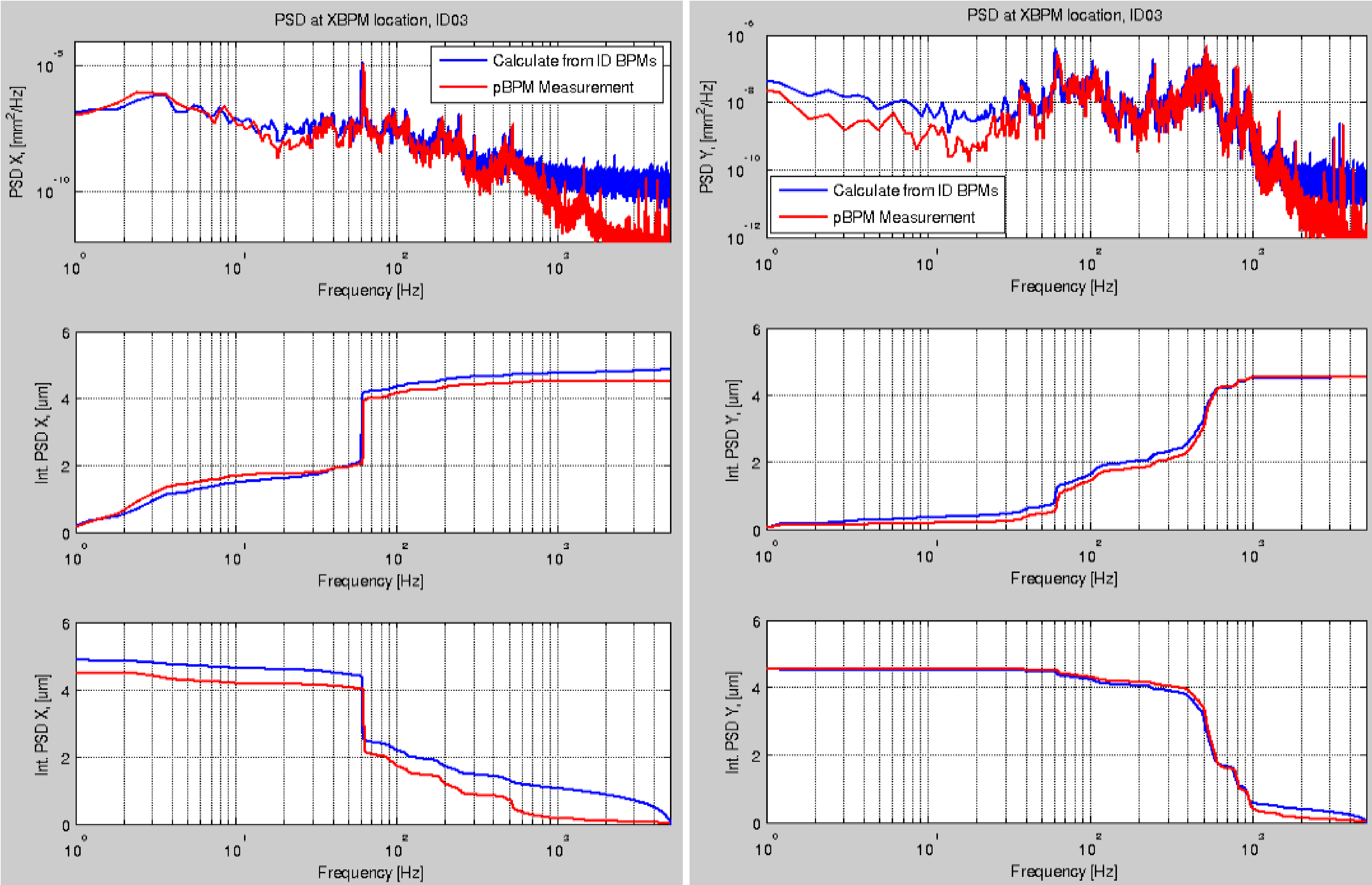
Exclude dispersive BPMs from the averaged spectrum calculation

RMS Motions Along the ring



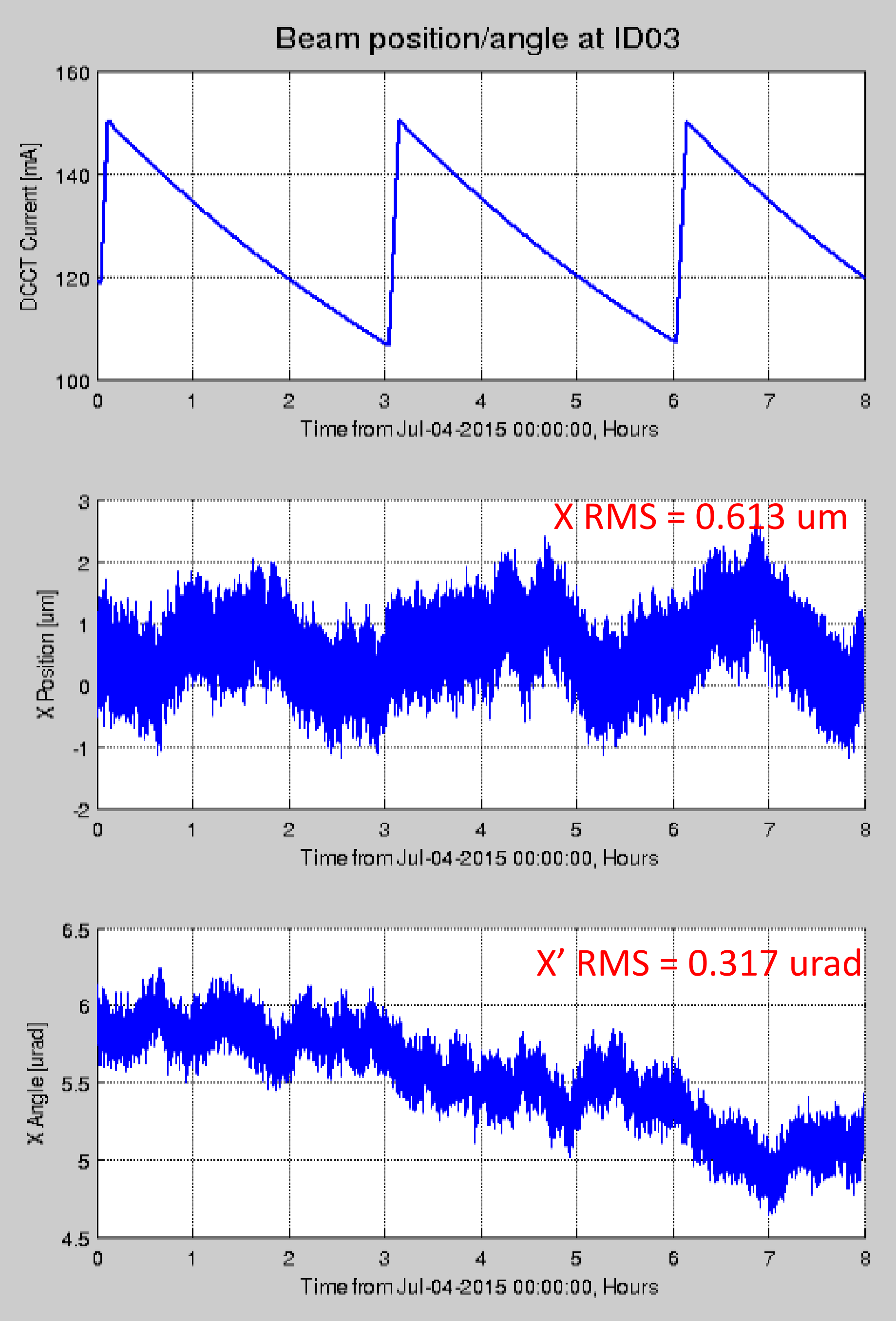


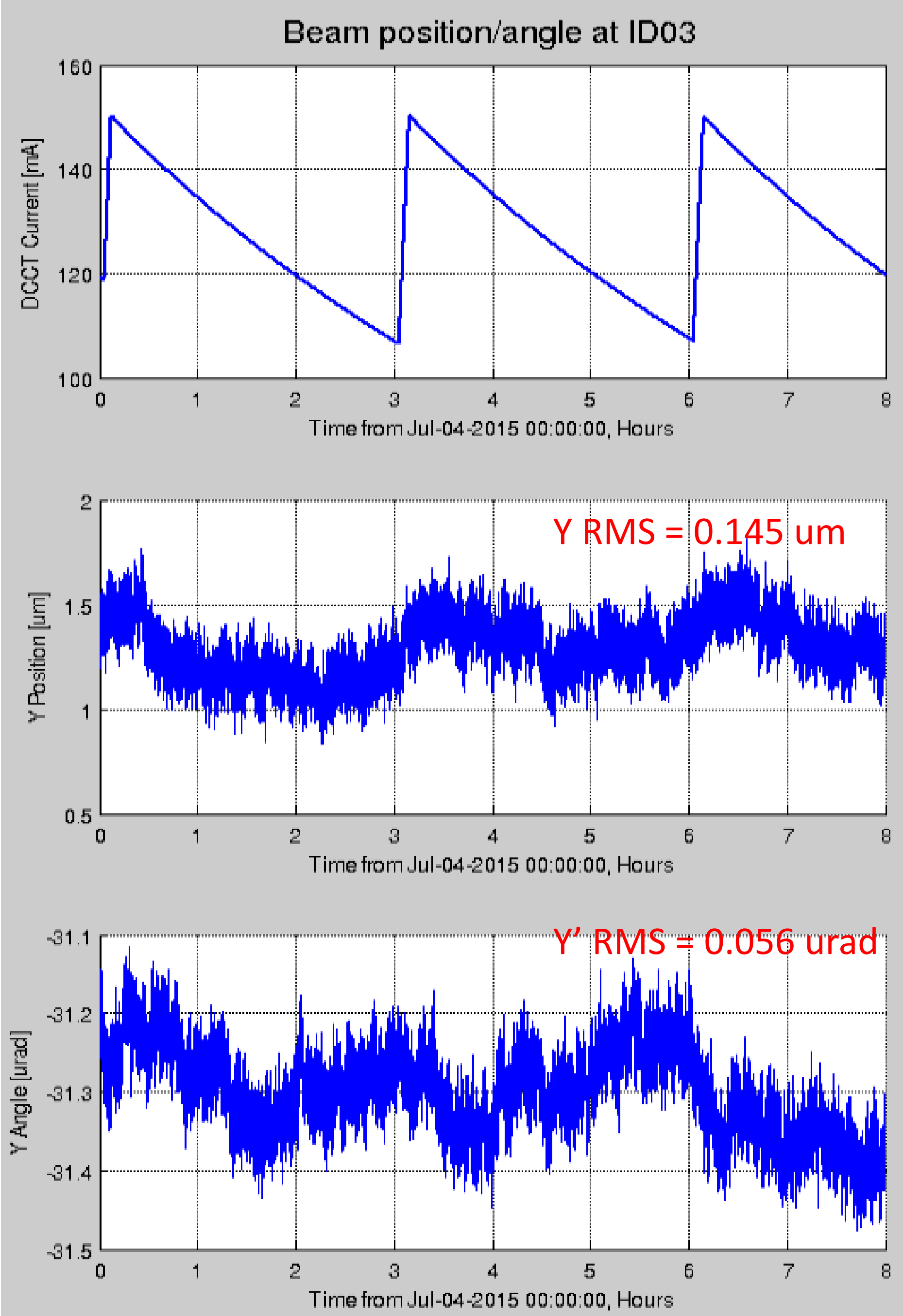
Comparison of PSD spectrum (calculated from ID BPMs vs. pBPM measurement)



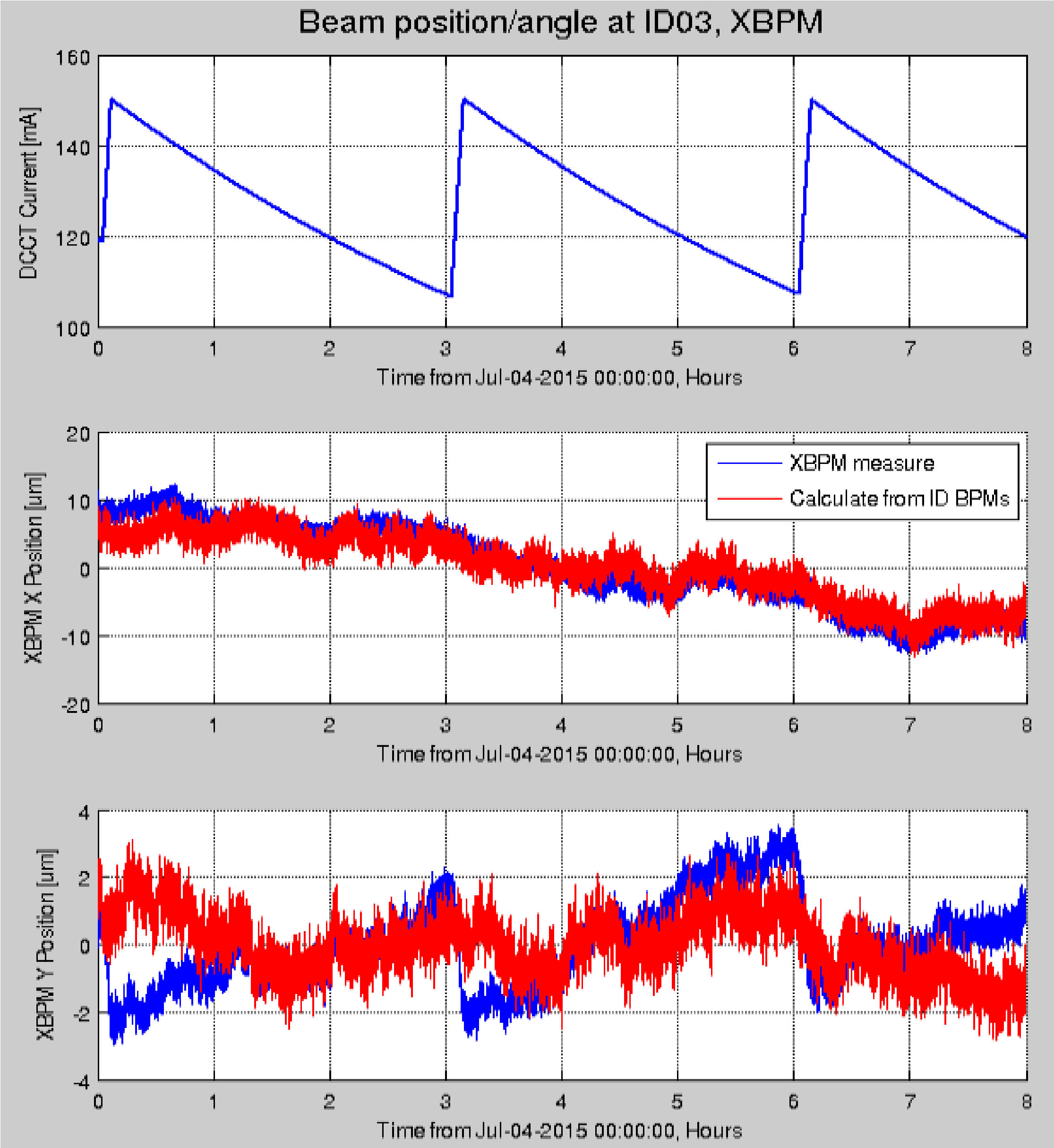
Looks like pBPM electronics has less noise, especially for >1kHz range.

Long term stability at ID source point





Long term stability @ C03 pBPM

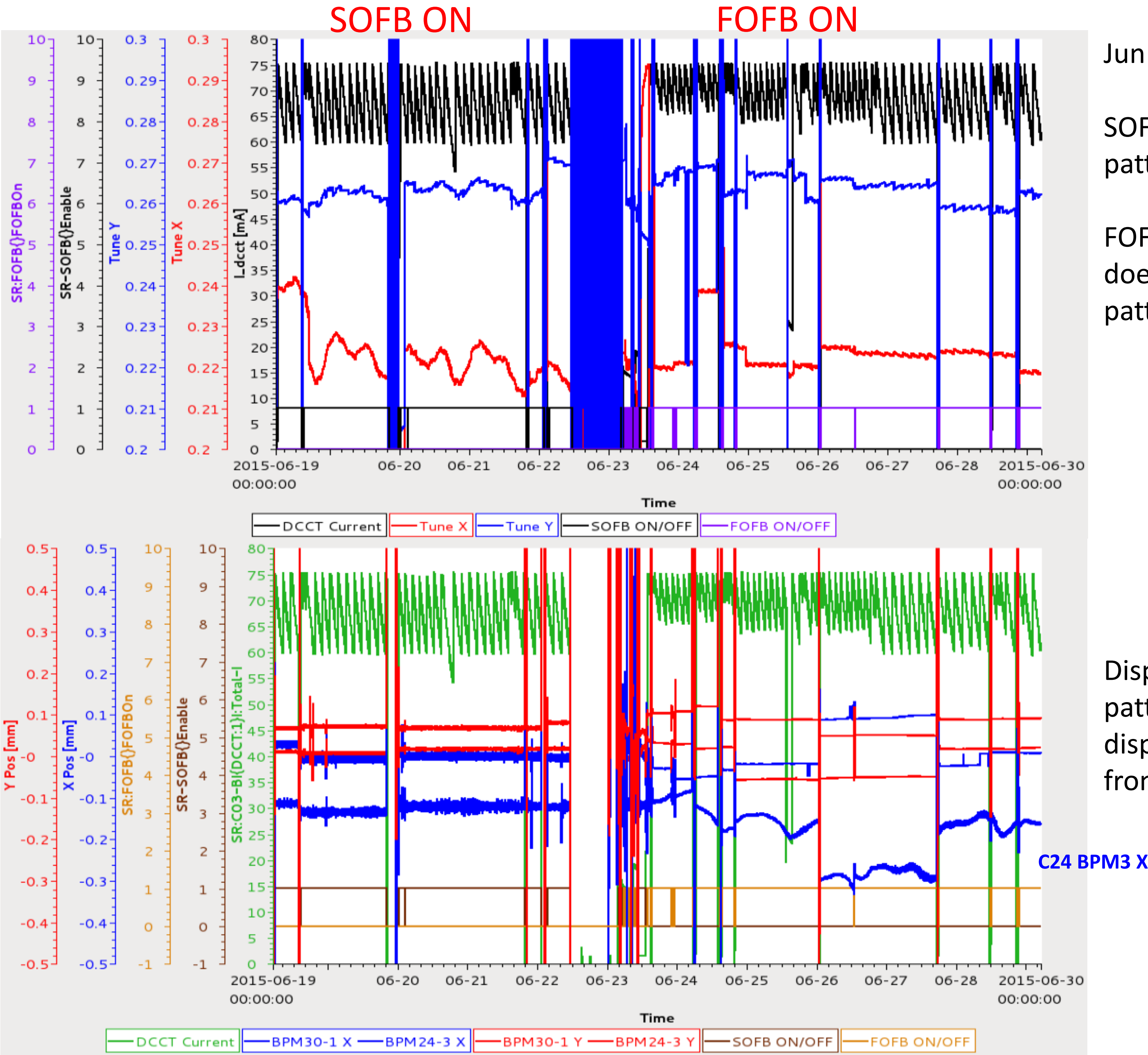


C03 ID gap fixed at 5.92mm

150mA user operation, beam current in 110 – 150mA range. Refill every 3 hours

xBPM position can be calculated from two ID BPMs on ends of the IVU, compared to xBPM direct measurement.

Tune/Orbit history with SOFB and FOFB



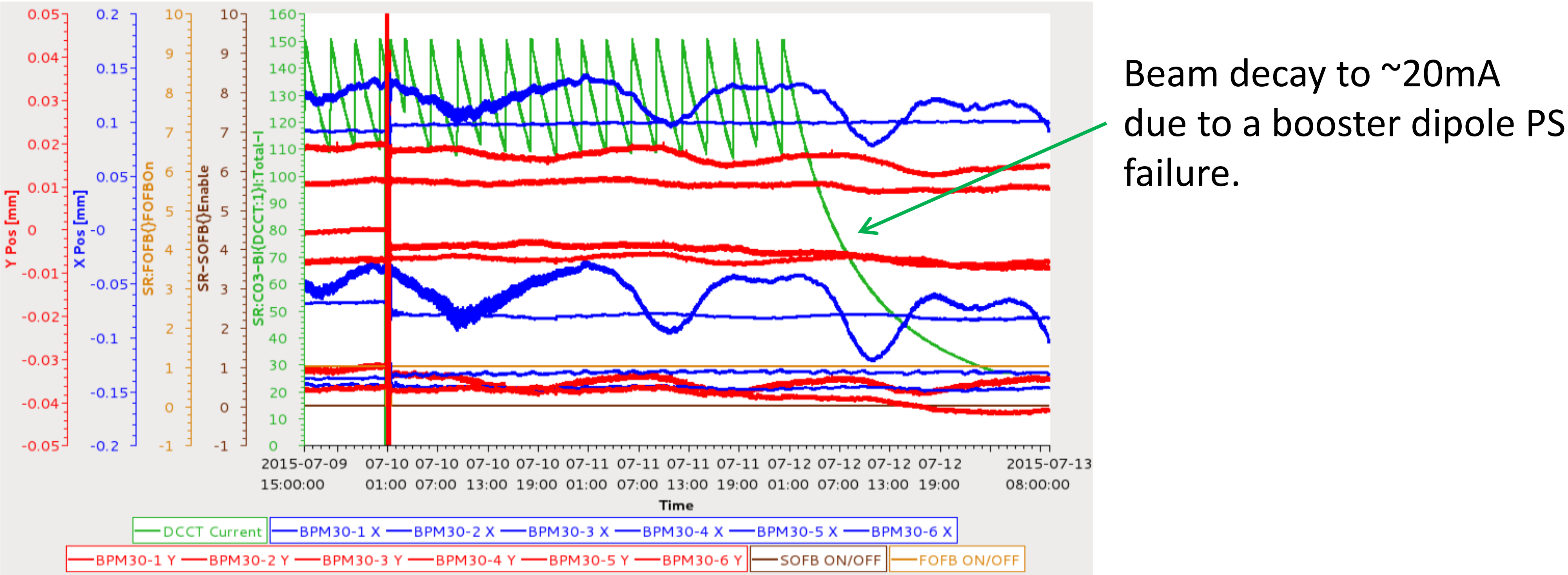
Jun 19-29 Tune history

SOFB ON, ν_x saw daily drift pattern.

FOFB ON, tune is more stable, doesn't see the daily drift pattern anymore.

Dispersive BPMs saw the daily pattern with FOFB ON. Note dispersive BPMs are excluded from Horizontal FOFB.

Orbit history data during 150mA user run (Jul 9-13, 2015)

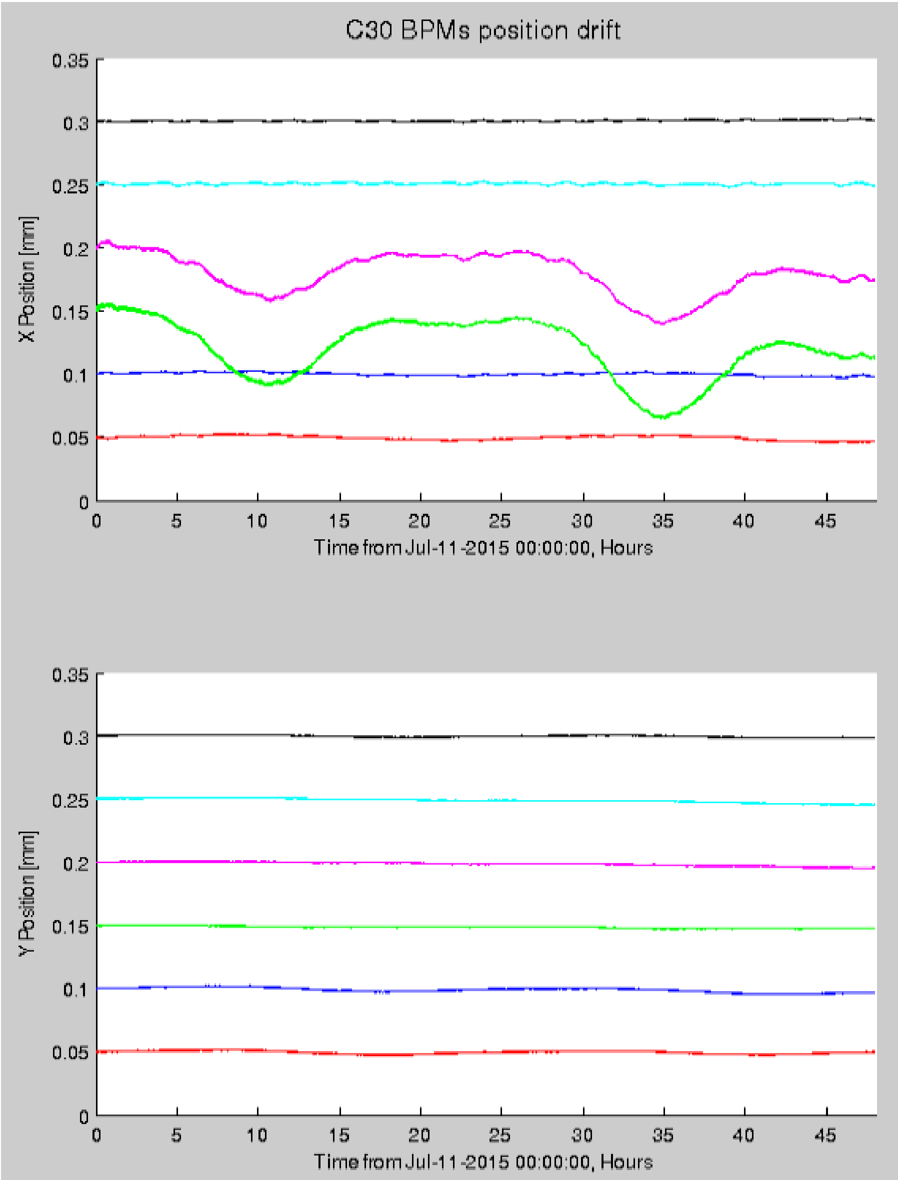


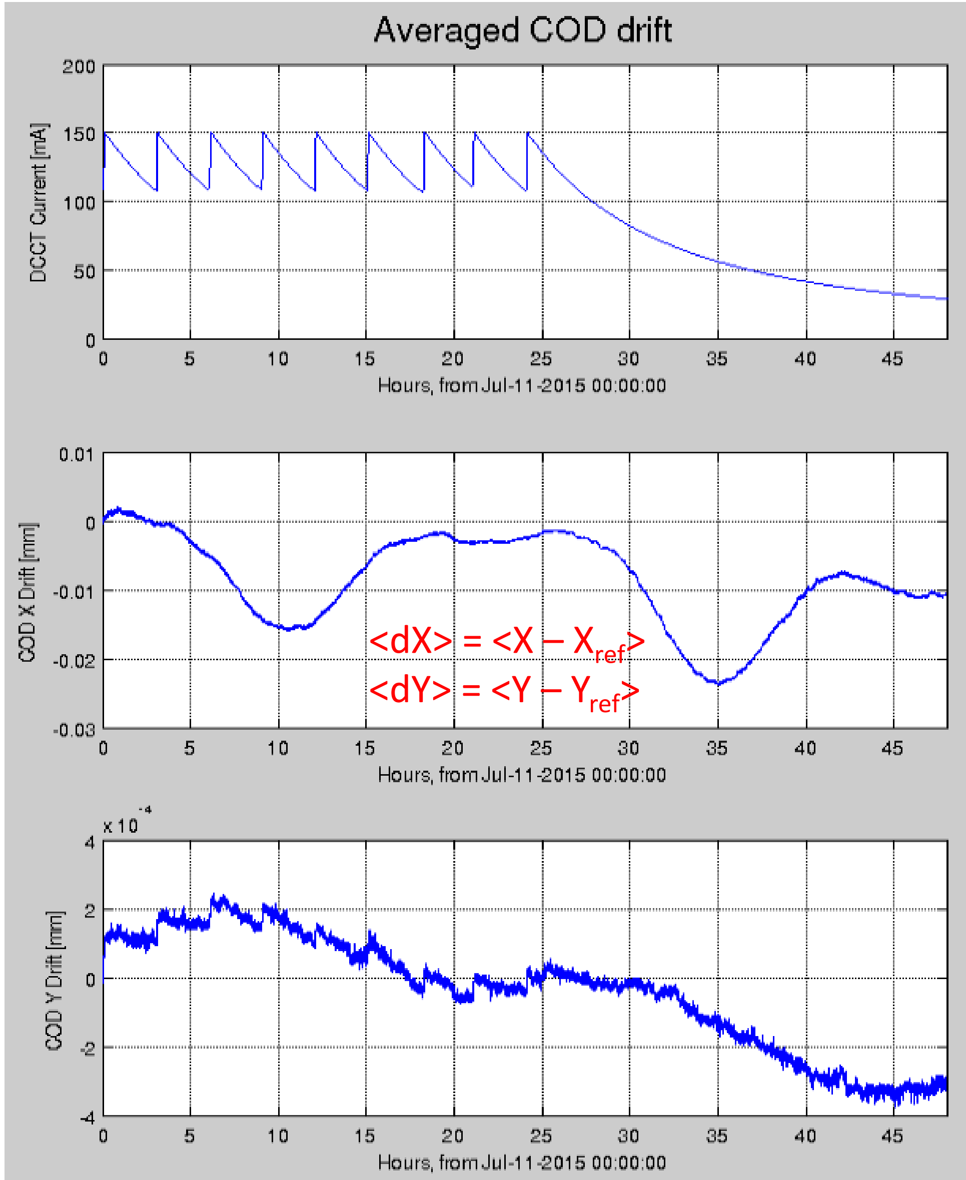
6 BPMs X/Y positions from C30 were plotted

Dispersive BPMs (BPM 3,4) saw clear daily drift pattern. Not weather or tunnel temperature related.

Max. drift ~ 50 um at BPM #3 with dispersion ~ 0.424m. This gives energy mis-match $\Delta E/E$ = 1.18e-4, which is corresponding to ring circumference change of 34 um (ΔFrf = 21 Hz)

Drift valleys seems agrees with the nearby harbors high tides. One valley observed but there should have two high tides daily. Continue investigating …





C30 six BPMs X/Y positions for two days

Vertical offset adjusted to see the drift pattern easier

Averaged COD drift, take first COD as reference, check the COD drifting for two days.

X/Y are vectors including 180 BPMs readings

Summary

- In-house developed NSLS2 BPM performs well during machine commissioning and operations.

- Beam orbit spectrum has been characterized with BPM FA data. Without FOFB, beam RMS motion was ~20% of vertical beam sizes. Once FOFB commissioned, the RMS motion is suppressed to ~5% of beam sizes.

- Beam stability at ID source point has been analyzed using two ID BPMs, and compared to xBPM direct measurement.

- Excellent long term stability (~8 hours) was observed at ID center ($Y_{rms} < 200$ nm, peak to peak ~500nm). Dispersive BPMs saw daily drift pattern which is likely due to tidal effect.