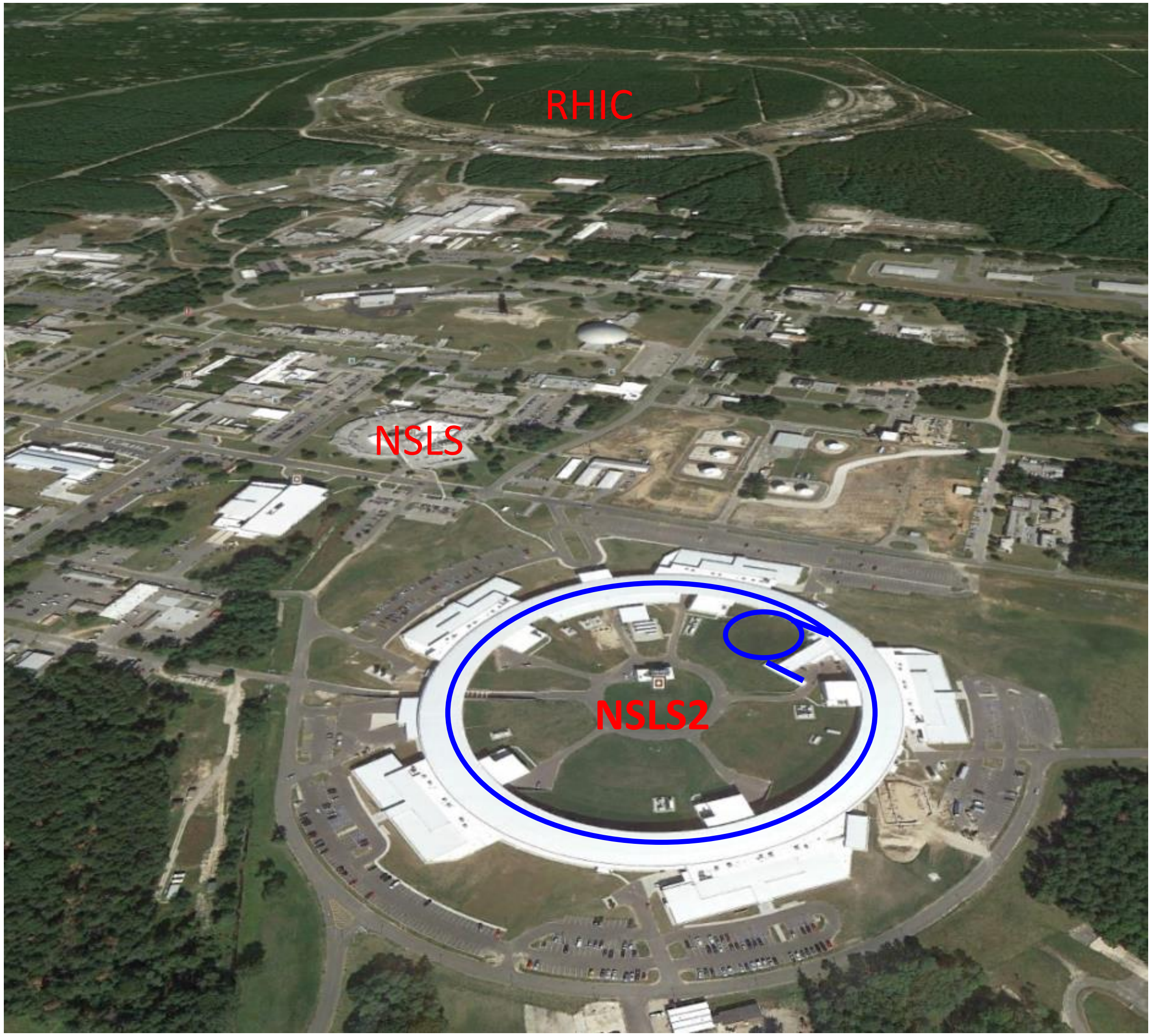
NSLS2 Diagnostic System Commissioning and Measurements

Weixing Cheng, on behalf of NSLS2 diagnostic group and commissioning team

3rd International Beam Instrumentation Conference

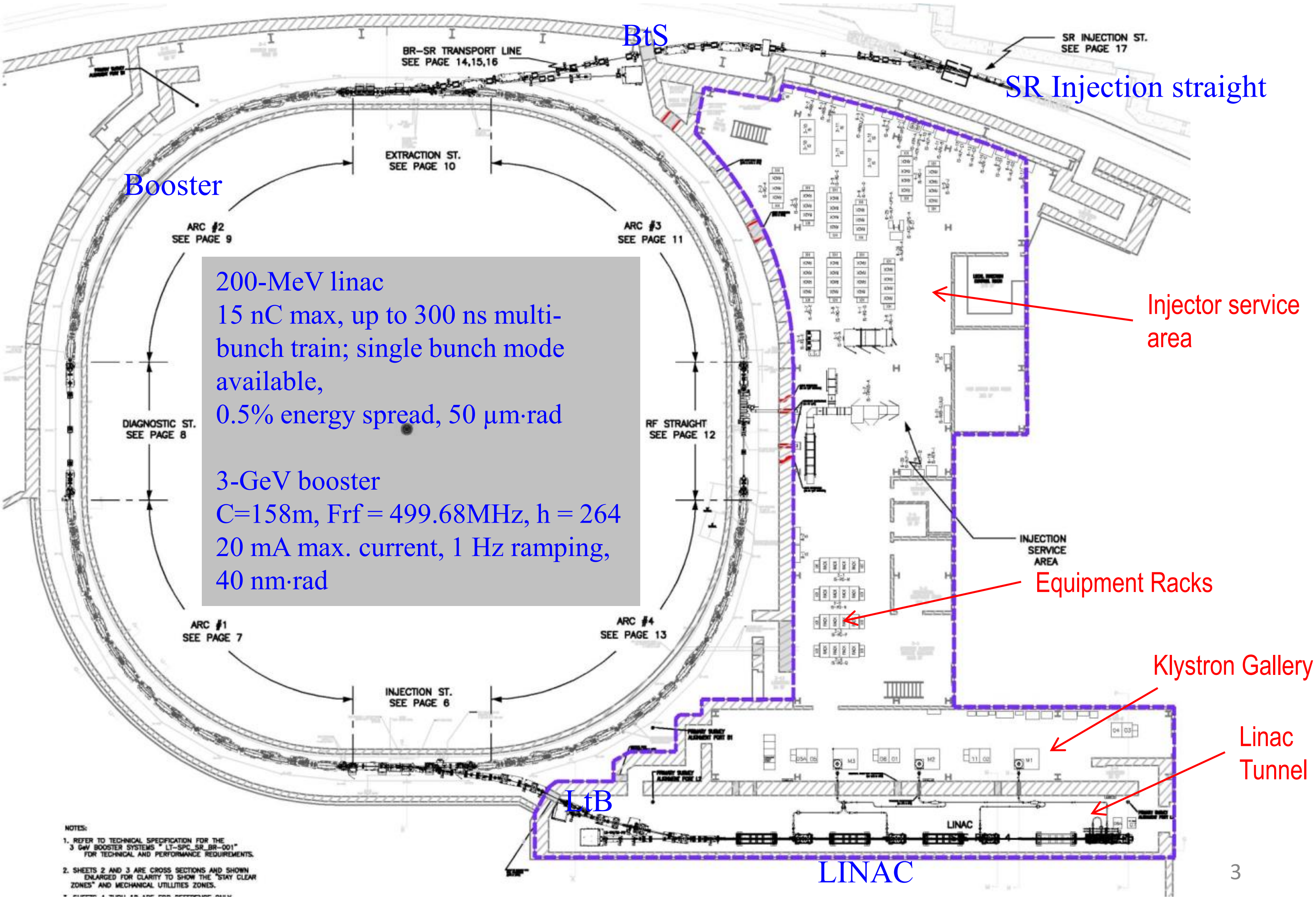
Monterey, California, USA, Sep. 14-18, 2014



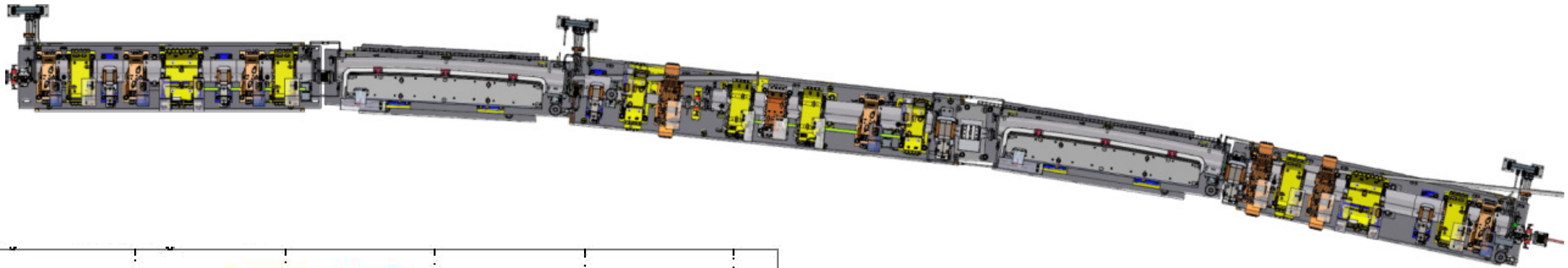
Outline

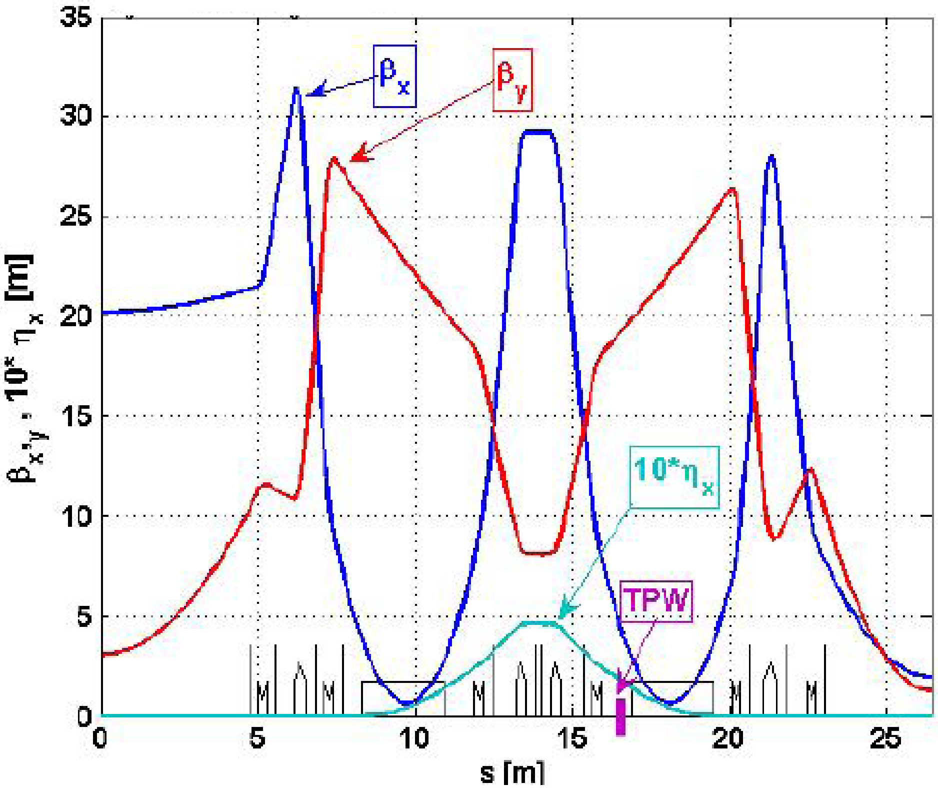
- NSLS2 introduction and commissioning overview
- Diagnostic systems commissioning with beam
  - Button BPMs
  - Current monitors (FC, WCM, FCT, ICT, DCCT, FPM)
  - Profile monitors (Screen, SLM)
  - Other diagnostics (Tune, BxB feedback, LCM, … etc.)
- Machine measurements
- Summary

NSLS2 Injector



NSLS2 storage ring main parameters





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

Injector commissioning timeline

- Mar 26 – May 29 2012, LINAC commissioning. Mis-steering event happened.
- Nov 27 – Dec 6 2013, LINAC re-start

- Dec-6-2013, Start of booster commissioning
- Dec-7-2013, Beam through injection septum
- Dec-10-2013, First turn in the Booster
- Dec-17-2013, Circulating beam
- Dec-19-2013, Multibunch mode, better signals, 100 msec circulating beam
- Dec-20-2013, RF Capture- synchrotron sidebands observed
- Dec-28-2013, Complete injection fault studies, authorization to accelerate
- Dec-31-2013, 3 GeV achieved
- Jan-19-2014, Start Fault studies with circulating beam
- Jan-28-2014, Completed Fault studies with circulating beam
- Jan-29-2014, Authorization to extract to the dump
- Feb-1-2014, Fault studies in the BtS transport line
- Feb-19-2014, Booster commissioning complete successfully

SR Commissioning timeline

Phase 1, Mar 26 – May 12, PETRA 7-Cell cavity, DWs installed but not used

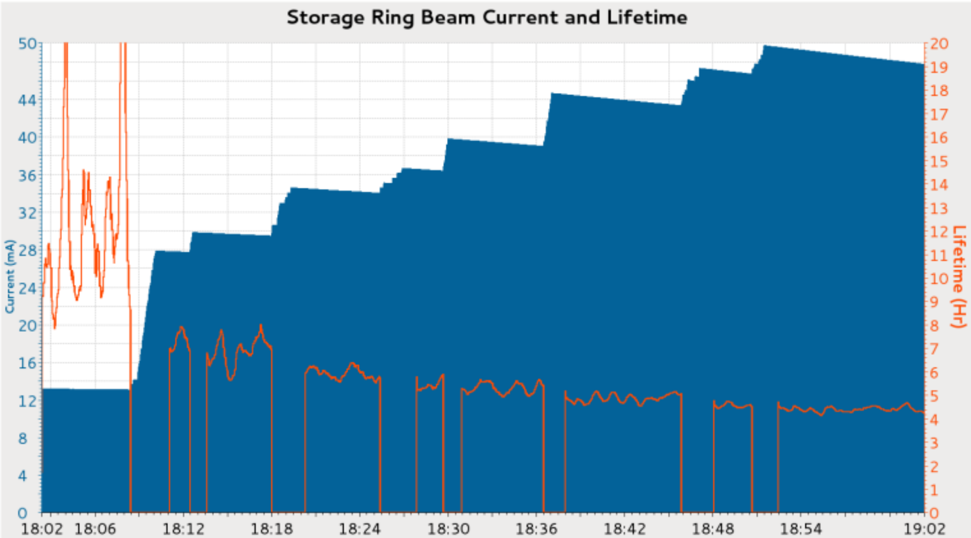
- Mar-26-2014, authorized to start storage ring commissioning.
- Mar-31-2014, first turns in the ring (2-3 turns)
- Apr-02-2014, discovered injection pulse kickers had wrong polarity which made injection difficult.
- Apr-03-2014, after fixing IS kickers, beam goes around for multi-turns (~10 turns). Observed partial beam lost at C10 BPM4.
- Apr-04-2014, beam circulating for ~ 100 turns
- Apr-05-2014, stored beam with injection DC bump. Sextupole ON, RF ON
- Apr-12-2014, accumulate beam w/o DC bump. Low capture efficiency
- Apr-16-2014, scanned dynamic aperture using IS kickers: ~ 4mm, 0.3mrad
- Apr-18-2014, achieved 5mA for short period of time
- Apr-23-2014, decided to inspect magnets and vacuum aperture near C10 Girder 4, after struggling with beam accumulation.
- Apr-24-2014, fixed leakage current issue for all dipoles. Found RF spring hanging in C10, in between first dipole chamber and flange absorber
- Apr-25-2014, re-start after fixing the C10 vacuum and dipole leakage current, beam accumulation to 1.5mA then to 5mA (limitation for fault study). Observed longitudinal/vertical beam instability.
- Apr-29-2014, 25mA beam stored in multi-trains

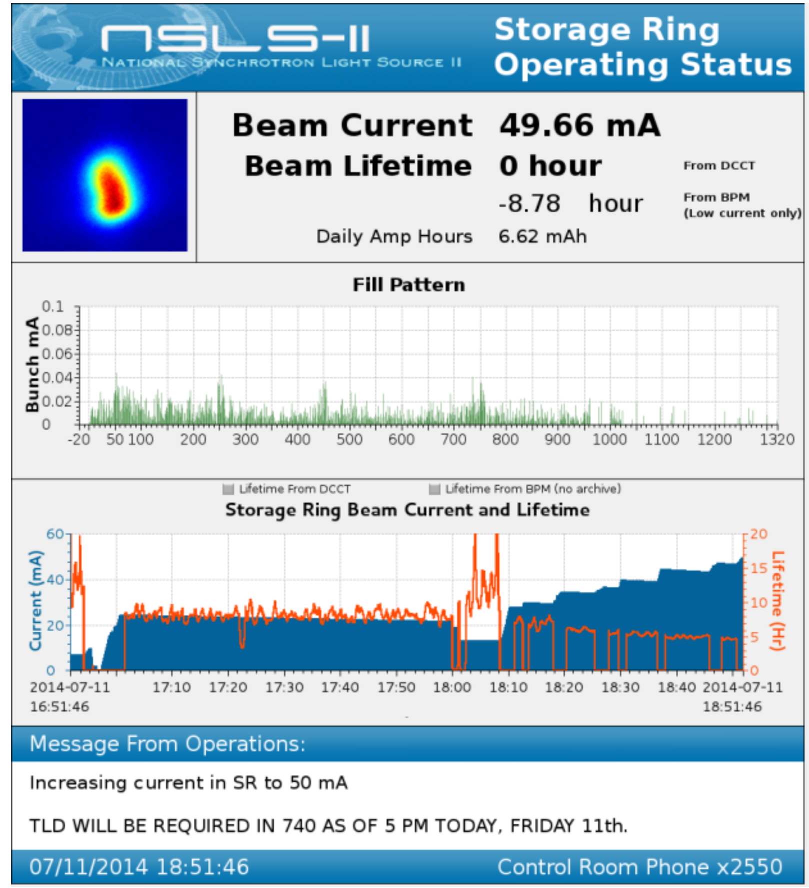
- May-14-2014, after the phase-I commissioning, found another RF spring in C08

Phase 2, Jun 30 – Jul 14, SC cavity, C03, C05 IVUs installed with gap fully open, DWs fully open

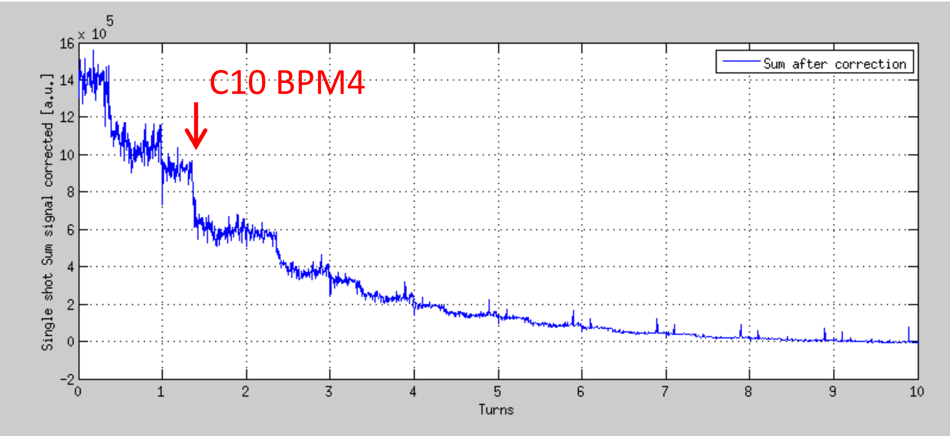
- Jun-26-2014, tunnel closed, SR cavity conditioning …
- Jul-02-2014, 25mA with SC RF
- Jul-11-2014, 50mA stored beam achieve with SC RF

50mA stored beam, Jul-11-2014, SC RF cavity, 1200kV





RF spring surprises



chengwx, 4/3/14, 6:20 am Show details

Great to see beam goes around multi-turns.

Whiling looking at BPM 4-button SUM signal. It looks beam lost partially near C10 BPM4 at every turn around. Suggest to look at the magnets near the area.

yli, 4/3/14, 6:52 am Show details

Ferdinand called in and suggested that we should turn on the K1 and K2 to balance the residual field of K3 and K4. Eric was contacted and he approved us to turn on K1 and K2. We will turn them on to see if beam can survive longer.

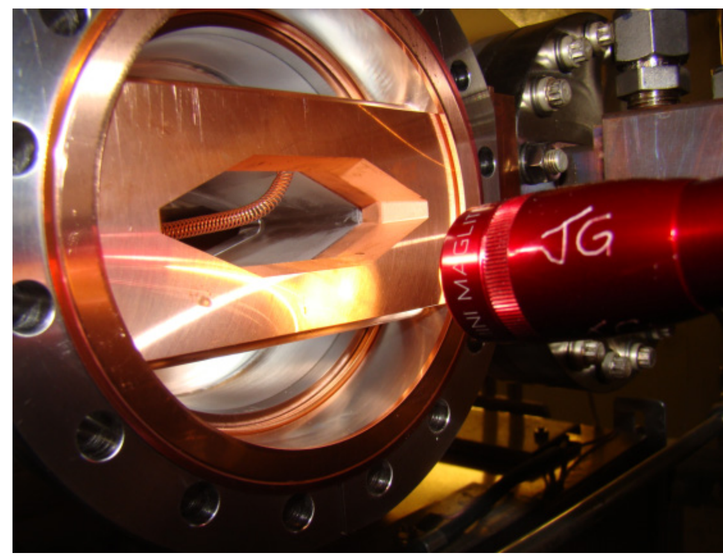
Weixing called in to notice us that a significant beam loss at cell 10 at each turn (see attached plot). The magnet settings around this region were checked, they look fine. We wonder if there is any physical aperture to scratch the beam there. Further investigation is needed to understand it.

First hint of partial beam loss found on Apr-03-2014, using BPM SUM signal. Beam was circulating for ~10 turns for the first time.

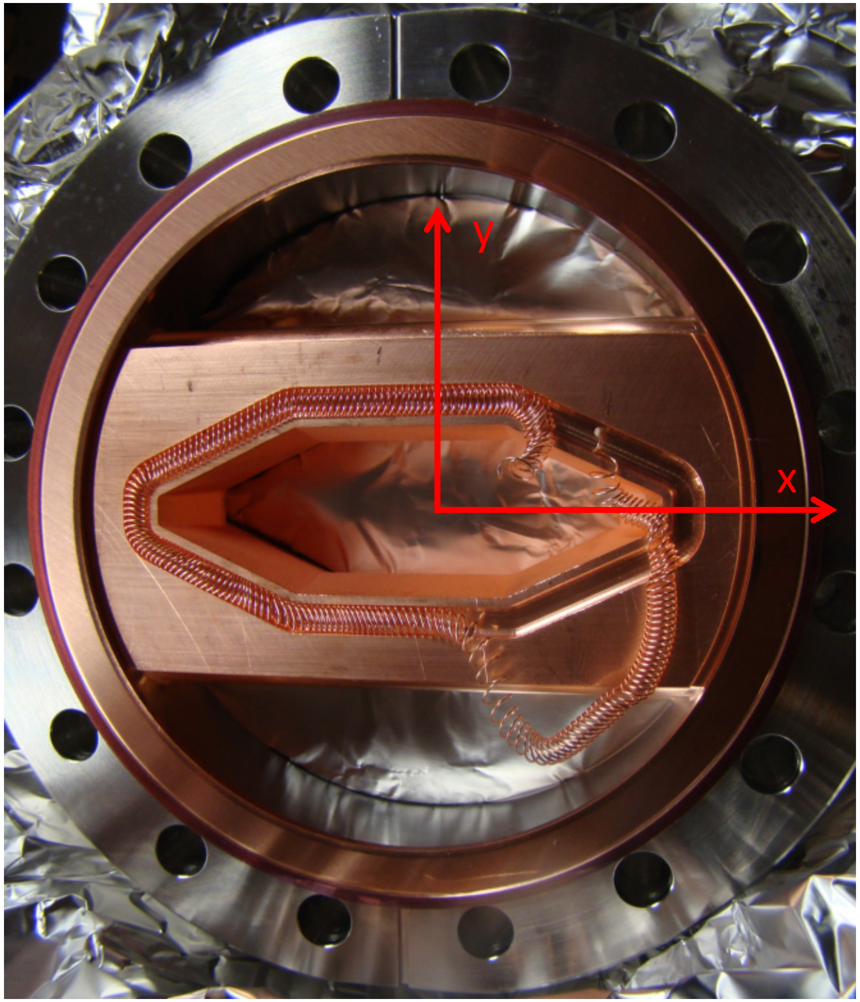
Struggled to get accumulated beam.

Other evidences shown obstacle in the vacuum near C10. Local bump sweep saw limited aperture; elevated radiation near the area when beam lost; vacuum activities etc.

Decided to open the vacuum on Apr-24 and we found the hanging spring at after first dipole in the cell.



May-14-2014, after phase-I commissioning.
C08 RF Spring, after the first dipole chamber. Flange absorber right upstream of the bellow.
The spring was hanging at top-outer corner. It’s melted probably due to dipole radiation.

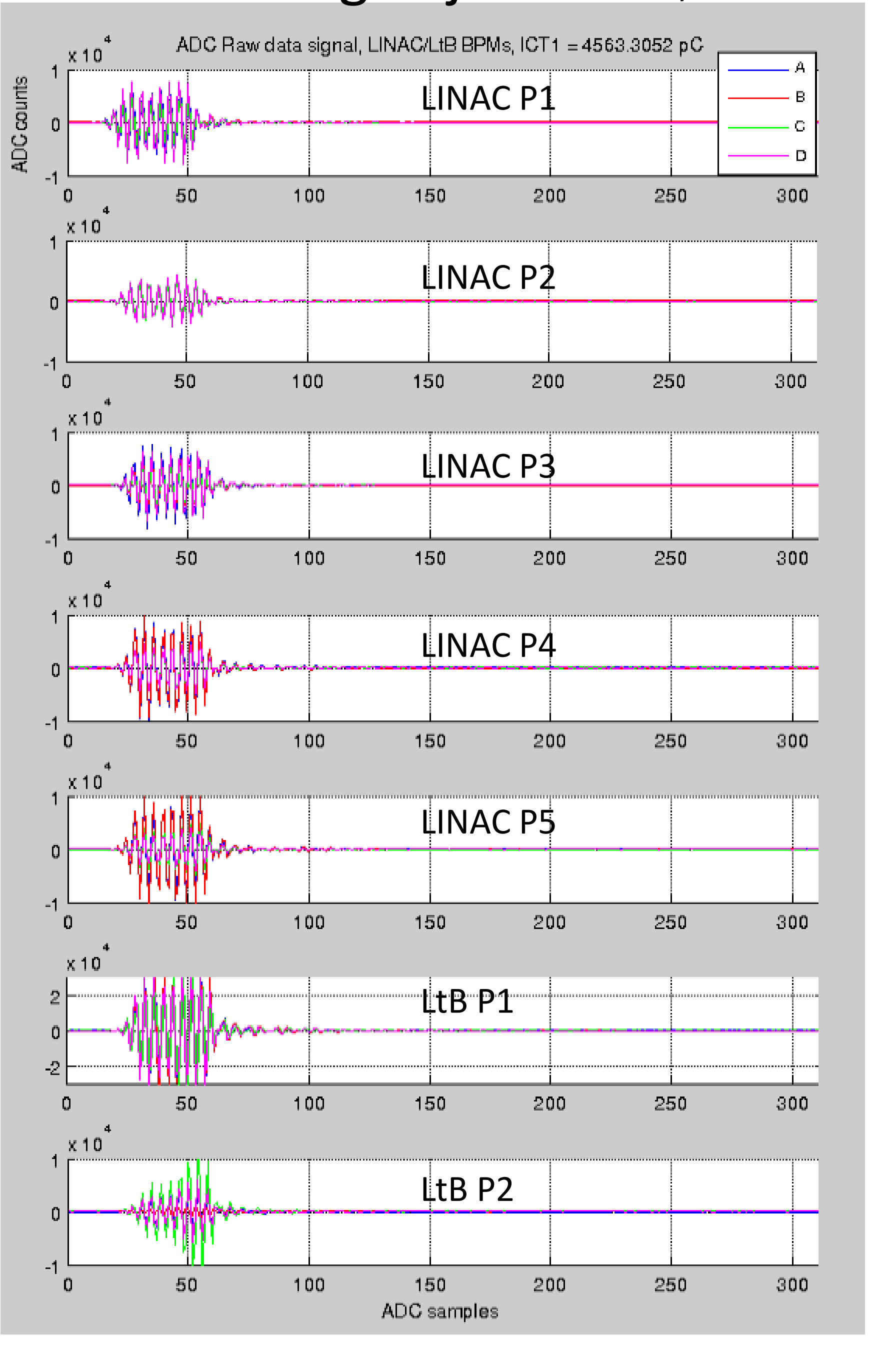


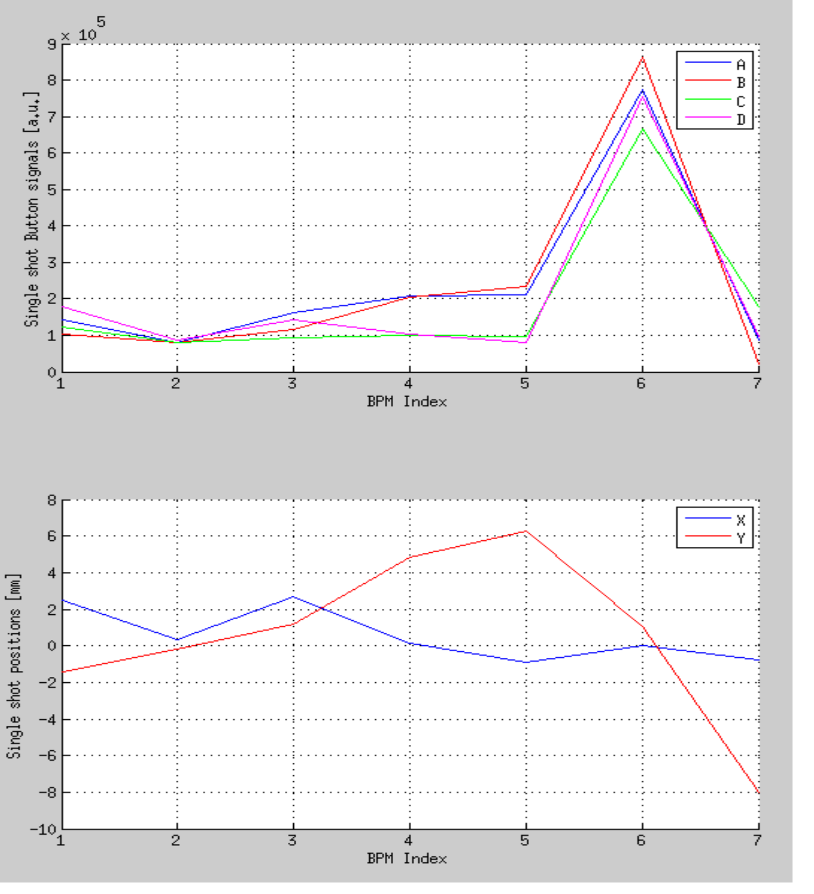
NSLS-II Diagnostics Systems

		LINAC FE	LINAC	Booster	LTB	BTS	SR
Position	Button BPM	1	4	37	6	8	180
	ID Button BPM						2 or 3 per ID
	Photon BPM						1 or 2 per BL
Current	Faraday Cup	1			2	1	
	WCM	1	4				
	FCT/FPM			1	2	2	1
	ICT				2	2	
	DCCT			1			1
Profile	Fluorescent / OTR Screen	2	4	6	9	9	1
	X-Ray Diagnostics beamline						1+1
	VSLM Diagnostics beamline			2			1
Other	Energy Slit				1	1	
	Tune Monitor			1			1
	BxB Feedback (H & V)						1+1
	Beam Loss Controls - Scrapers						3 H +2 V
	Beam Loss Monitors (Cerenkov BLMs and Neutron detectors)						5 CBLM 2 NBLM

1. Position monitors (button BPM)

BPM – timing adjustment, LINAC and LtB BPMs, beam to LtB dump2





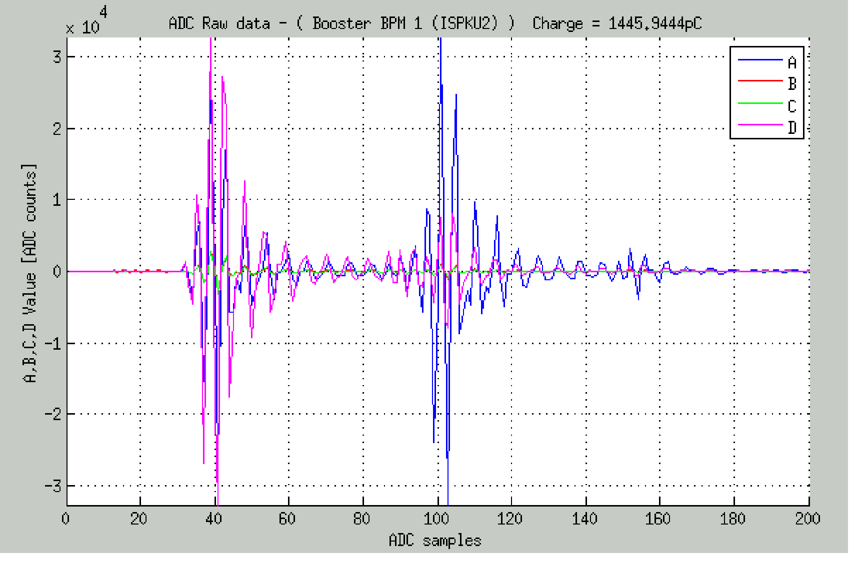
Dec-05-2013
Multibunch mode, LtB ICT reading 4.563 nC
Beam delivered to LtB dump2

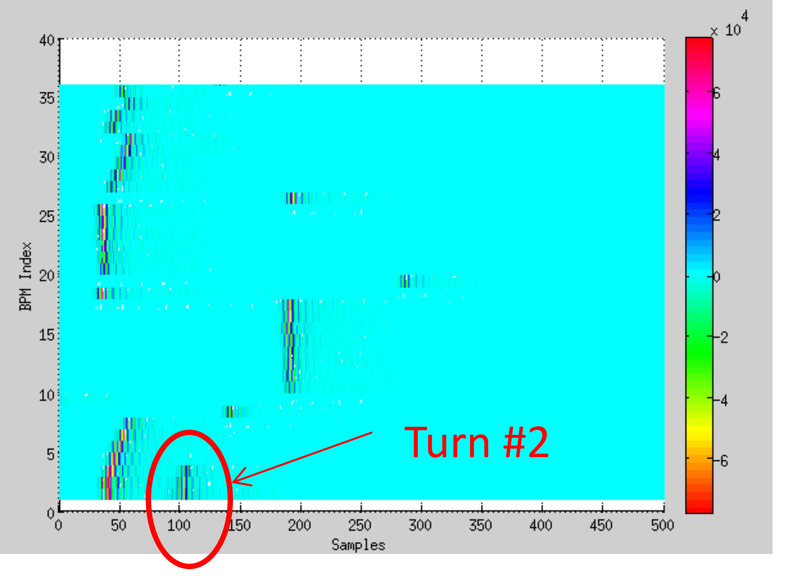
All BPMs set to 0 dB RF attenuation
BPMs were triggered on the global soft event, so that all BPMs get the same pulse data.

LtB P1 is close to saturate, larger button and smaller capacitance
Big loss from LtB P1 to P2. Note P2 has power splitter in the signal path.
Beam position at P2 is off a lot.

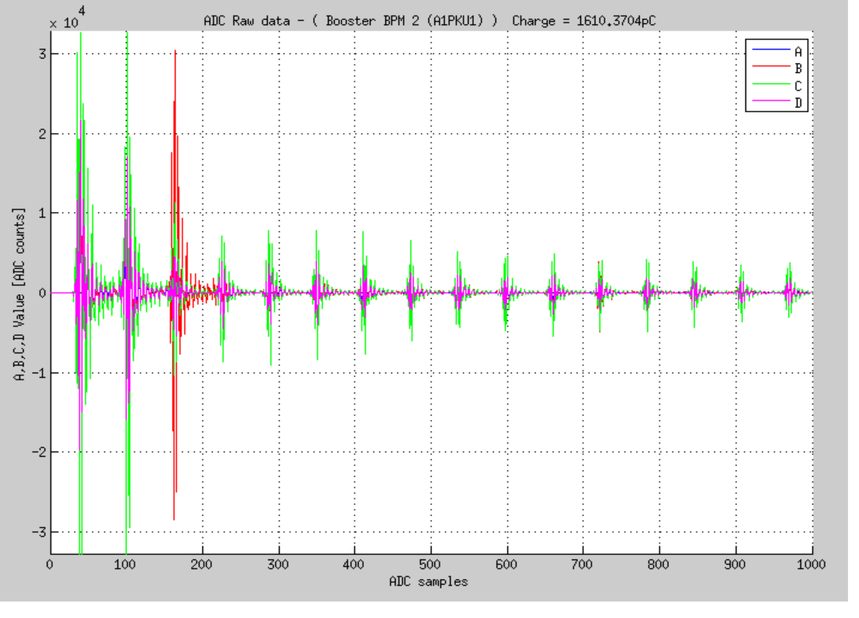
BPM - Booster first turns

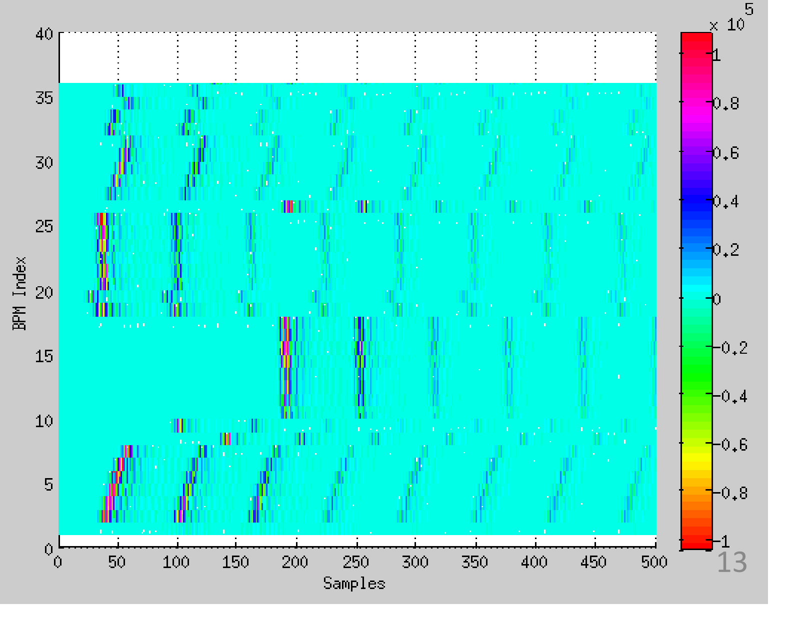
Dec-14-2013, ISVF1 lifted, 2nd turn signal observed on ISPKU2 and other 3-4 BPMs after injection straight.



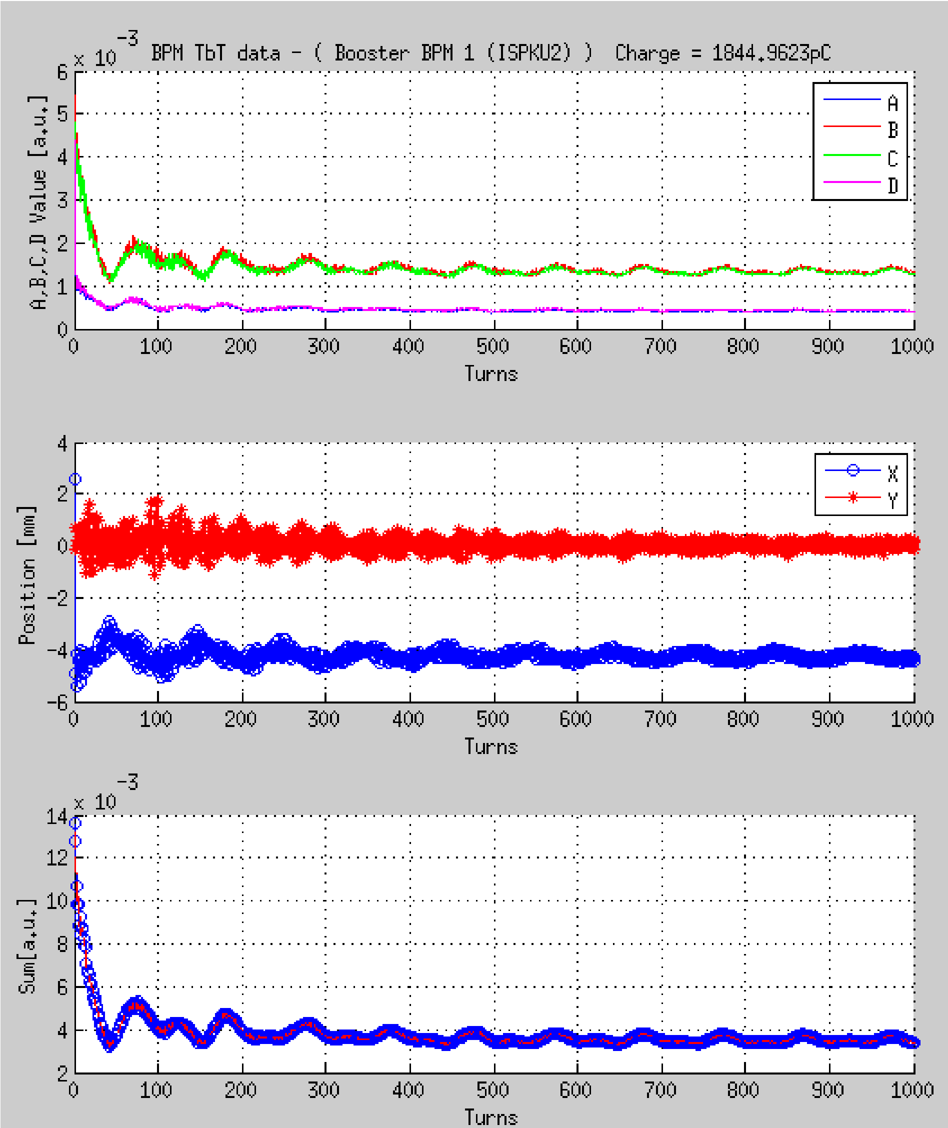


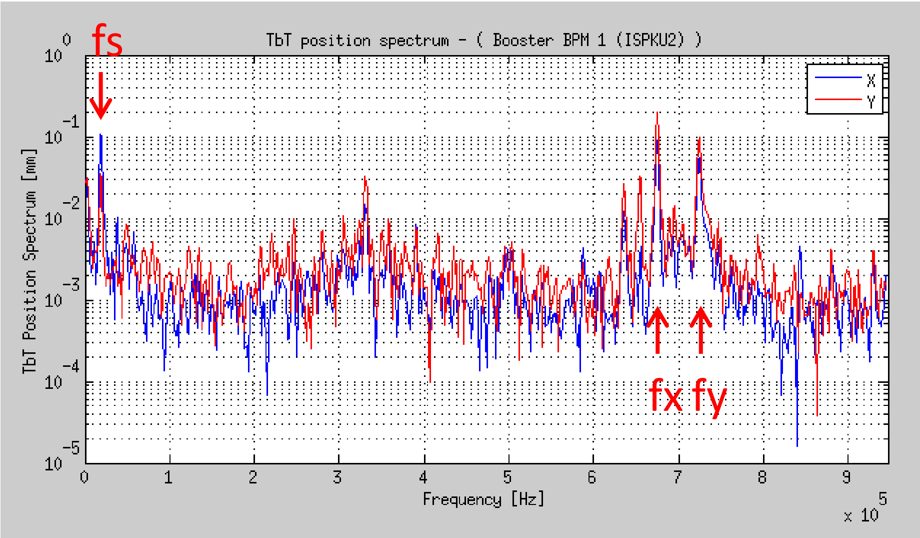
Dec-17-2013, ~23:00 multi-turns in booster





BPM - Booster stored beam, 200MeV, Dec-22-2013

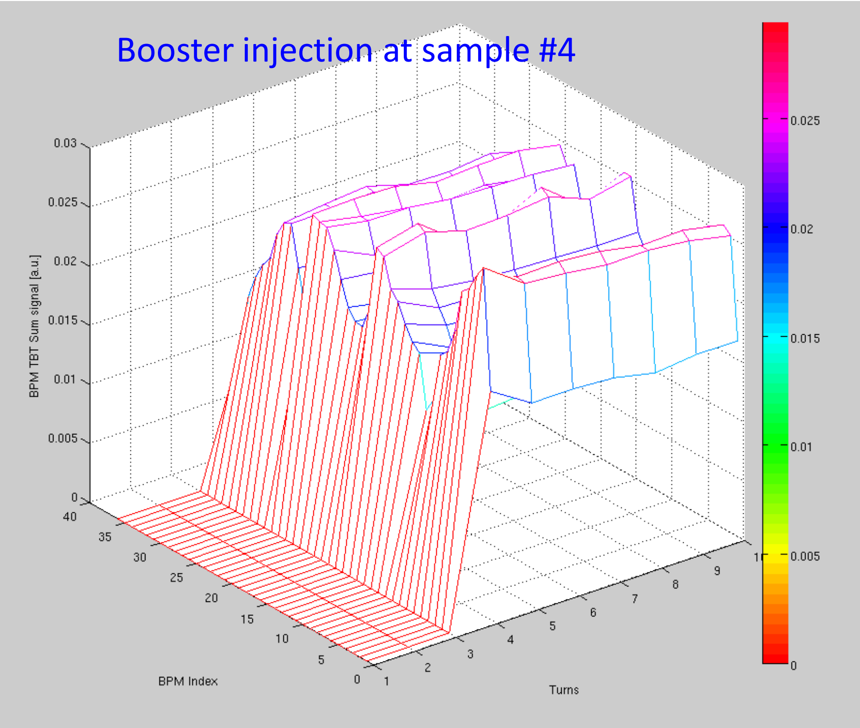


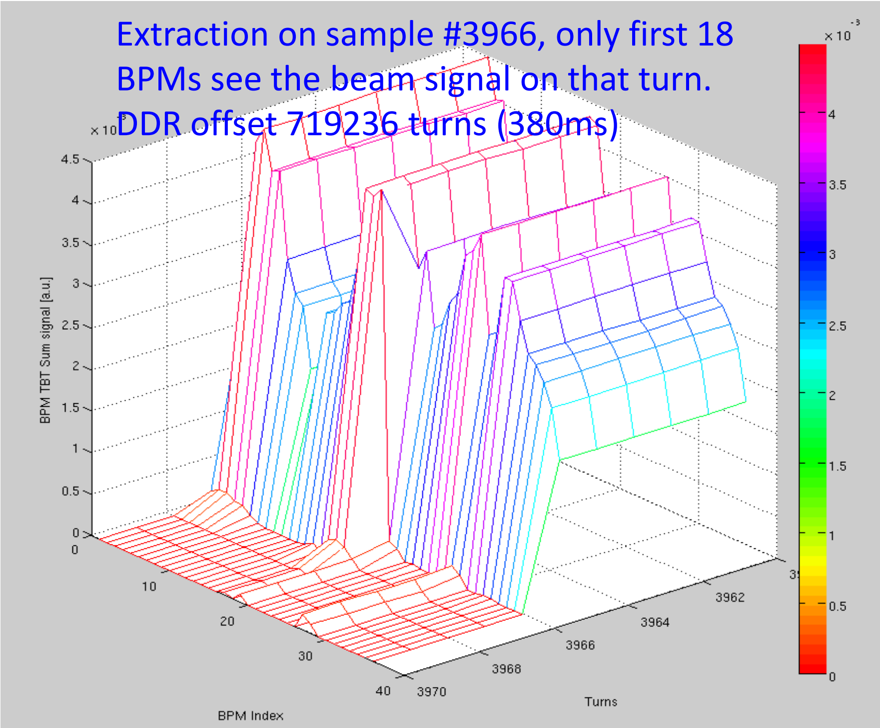


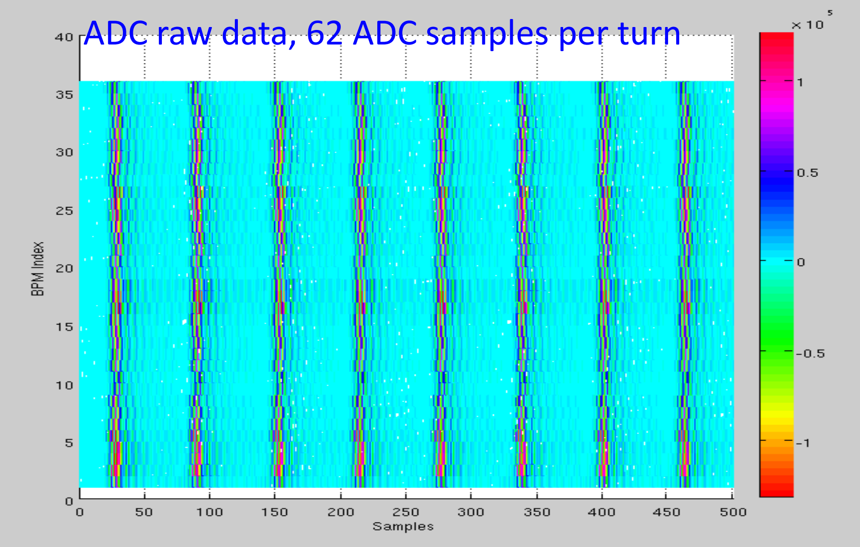
Turn 1:1024
NFFT = 1024
Fsam = Frev
df = 1.85 kHz

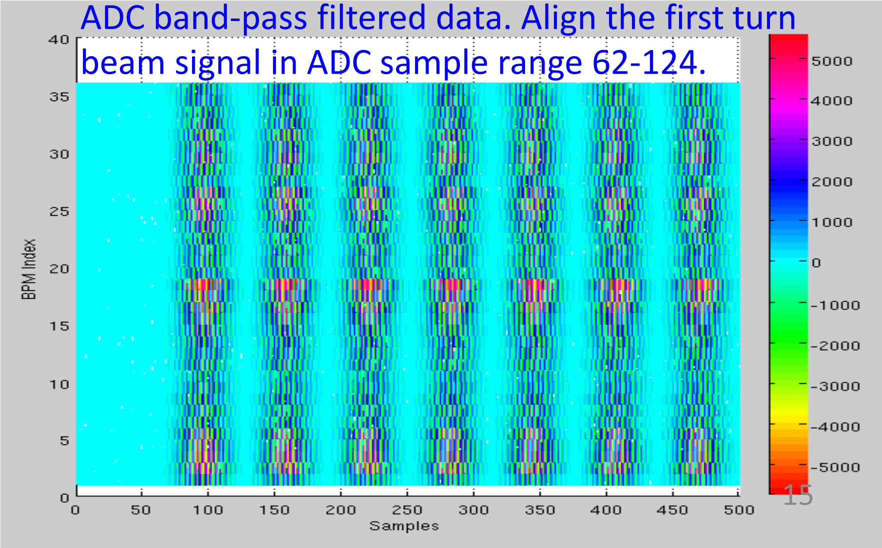
19.41kHz => fs
681kHz => fx
724.6 kHz => fy

Booster BPMs - Timing adjustment

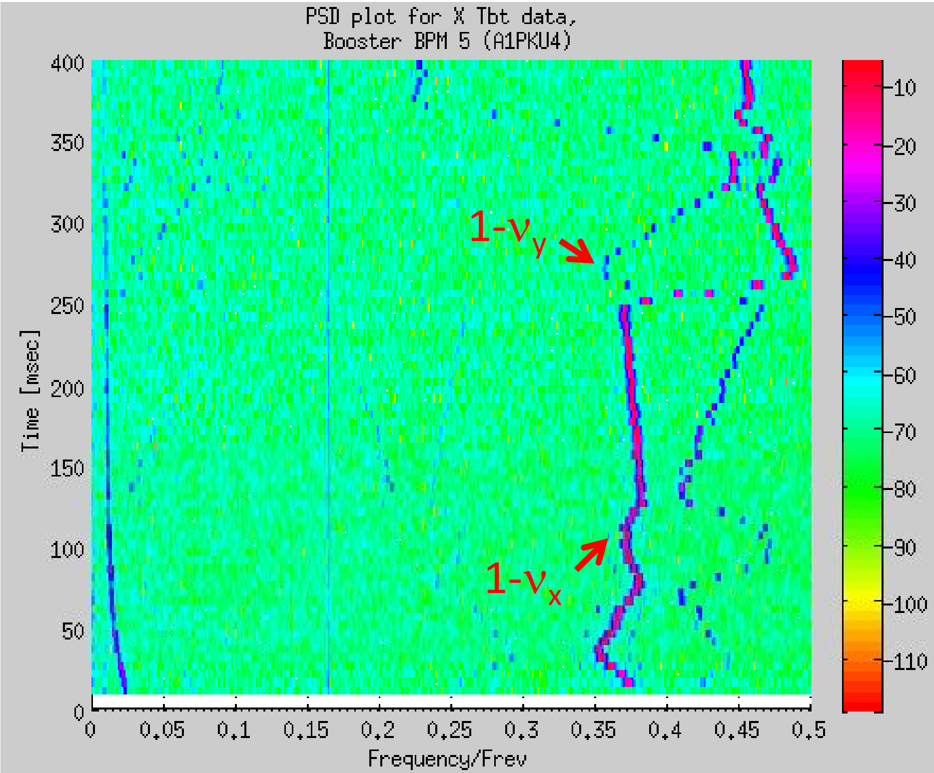


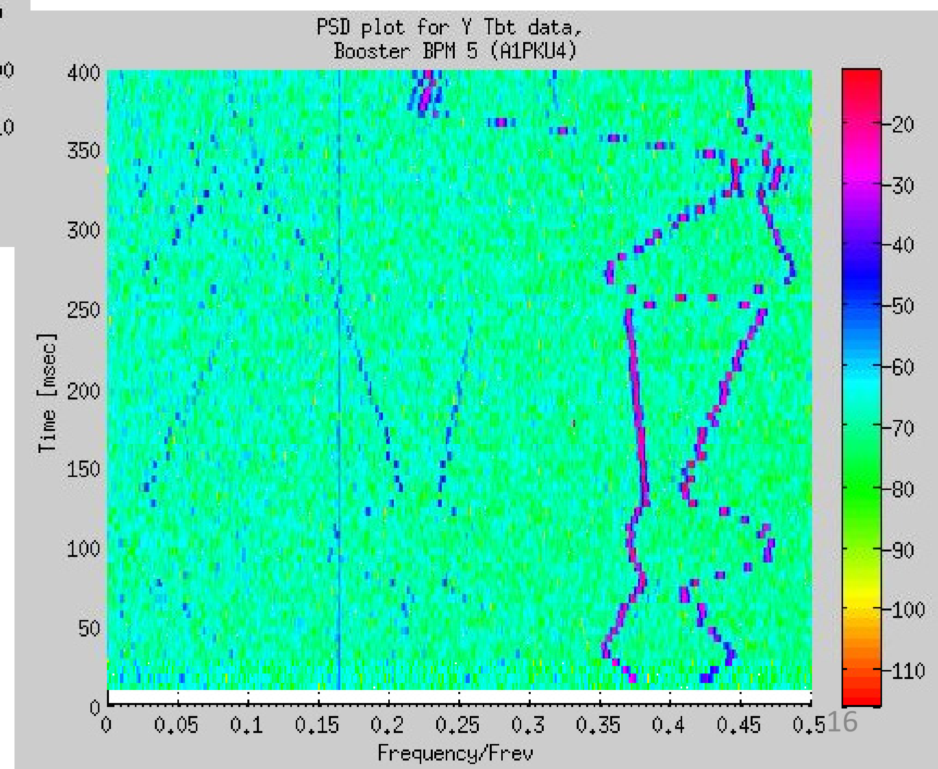






Booster BPM applications - Tune Spectrum



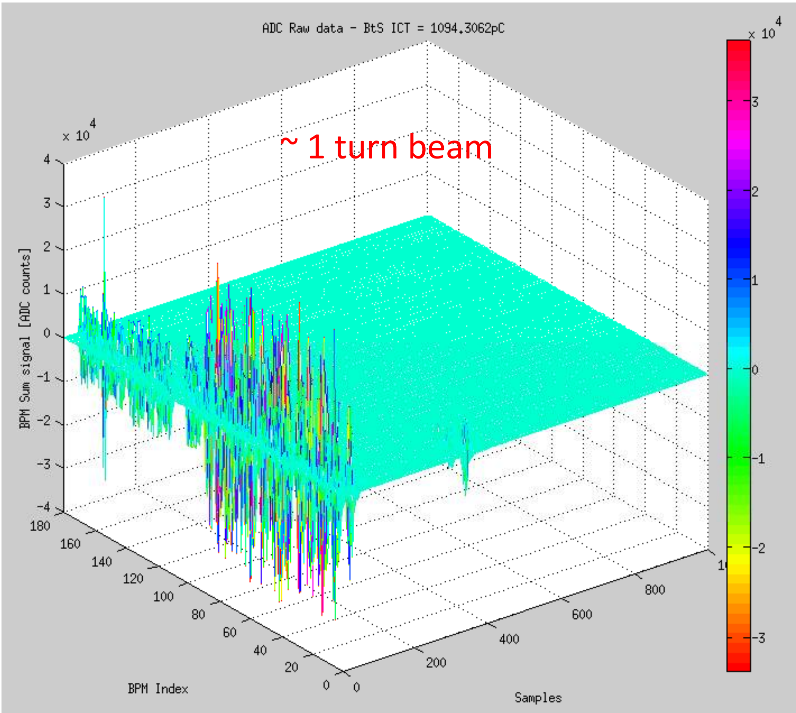


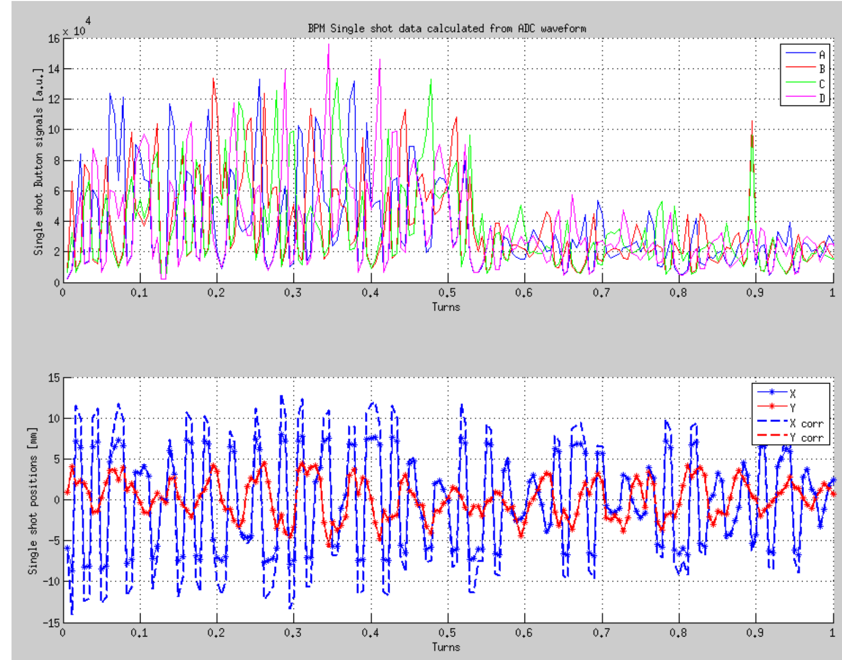
IS Kic #1
Kicker delay from 10:5:400 ms
Kicker amp from 1:0.1:4.9 kV

At each delay point, record the BPM TbT data.

Fractional tune is above 0.5

SR BPM – first turn



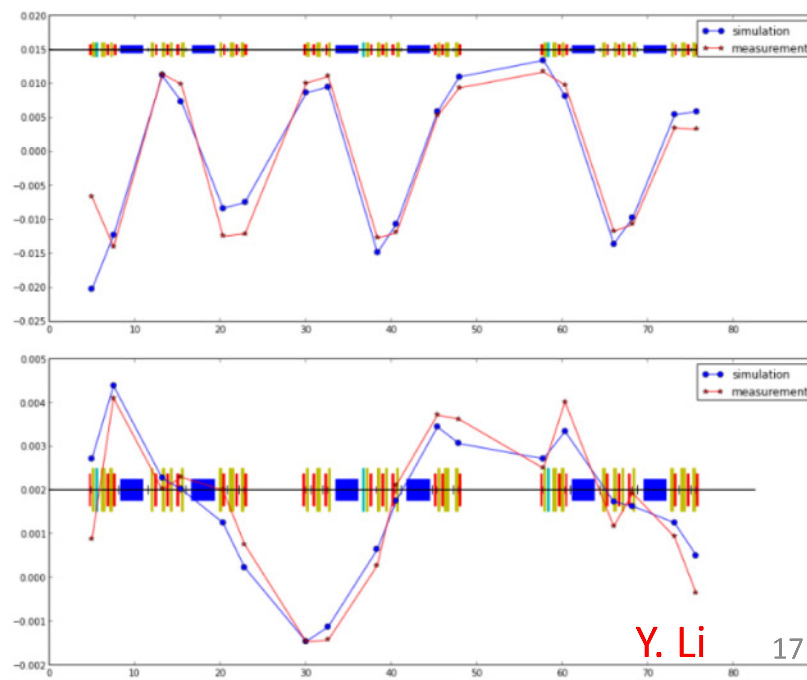


180 SR BPMs data triggered at: 04/02/2014,08:39:16

Struggling to get beam for multi-turns. Use the measured first turn beam trajectory and fit with machine lattice. Beam at the IS K4 exiting has 21mm horizontal offset, which is far from designed value.

Discovered that K3, K4 were kicking the beam in opposite direction.

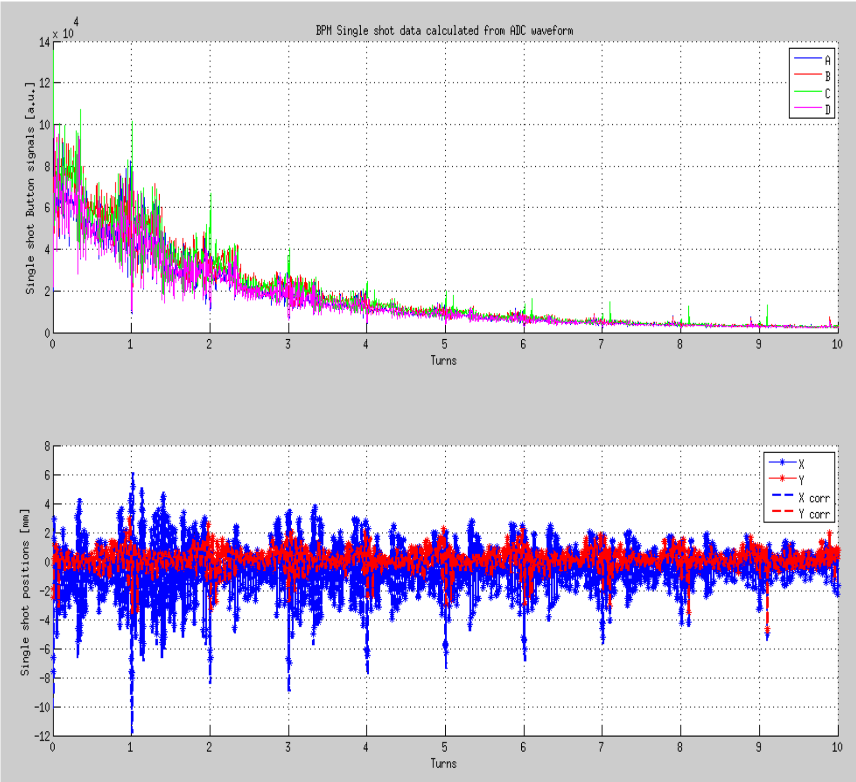
Note: First BPM data (C30 BPM1) is not trustable since beam is too far away from center (~20mm), BPM is in very non-linear range.



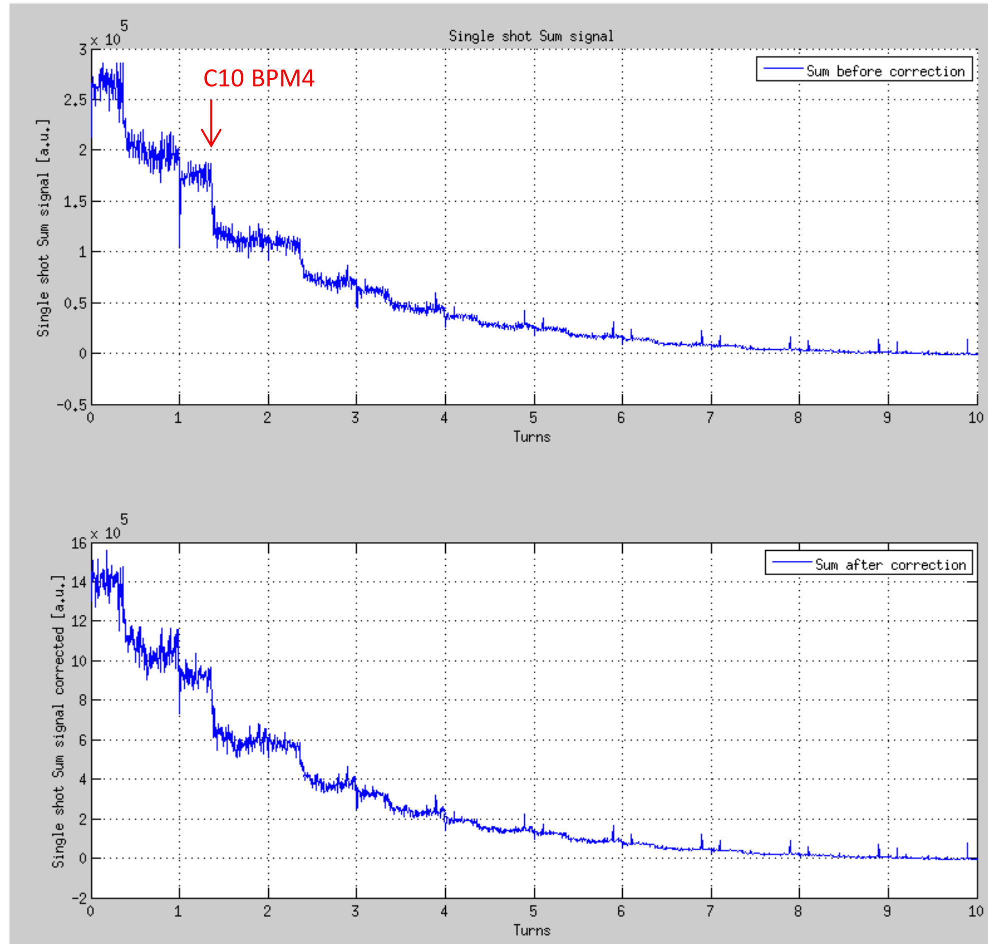
Y. Li

SR BPM – multi turns

Apr-03-2014, after fixing injection kicker polarities



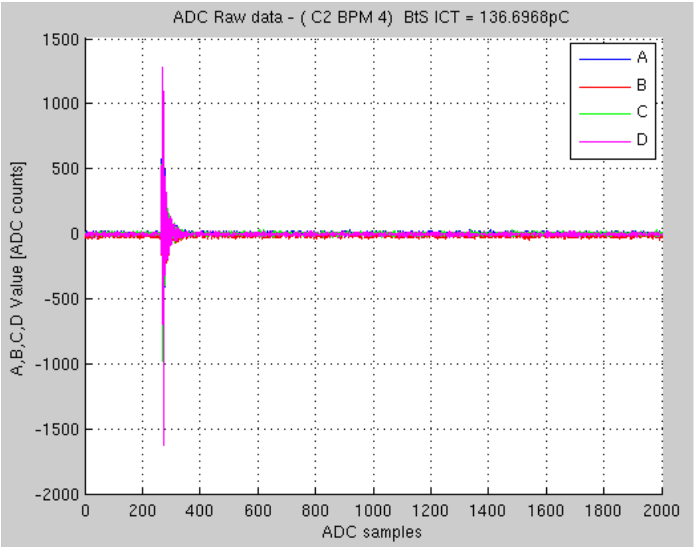
Beam lost partially near C10 BPM4 at every turn around.
This is the location where loose RF spring was found later.

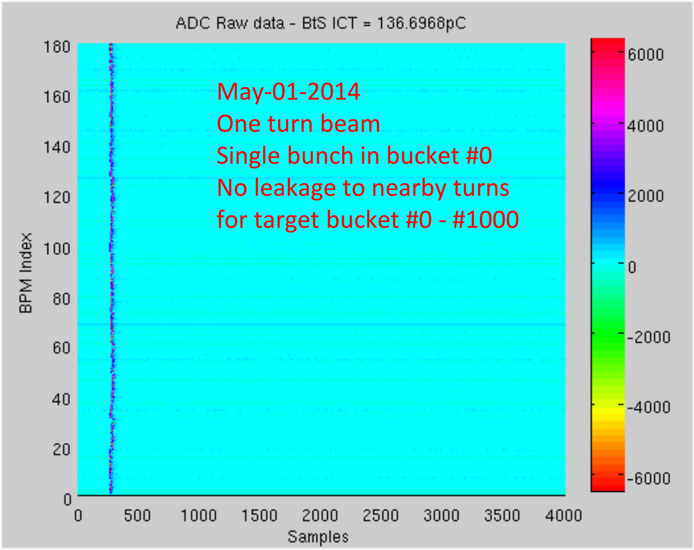


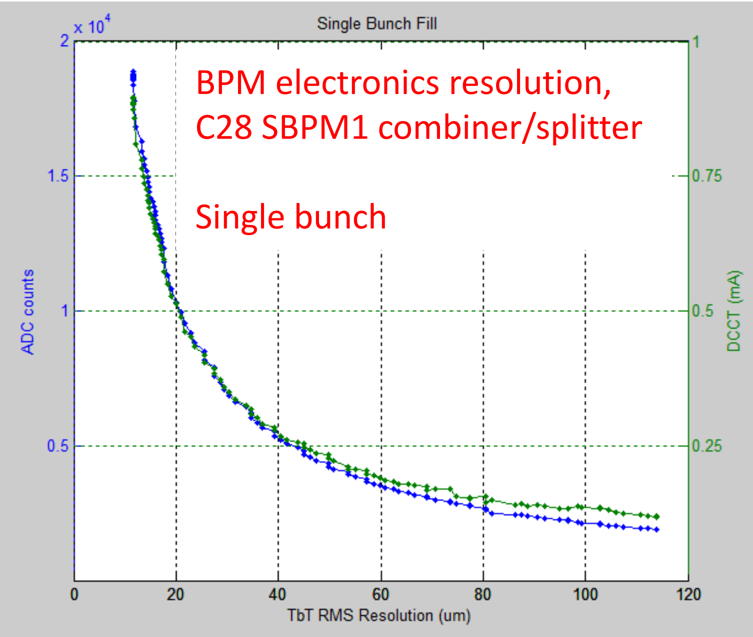
x/y position nonlinearity corrected using 5th order polynomial

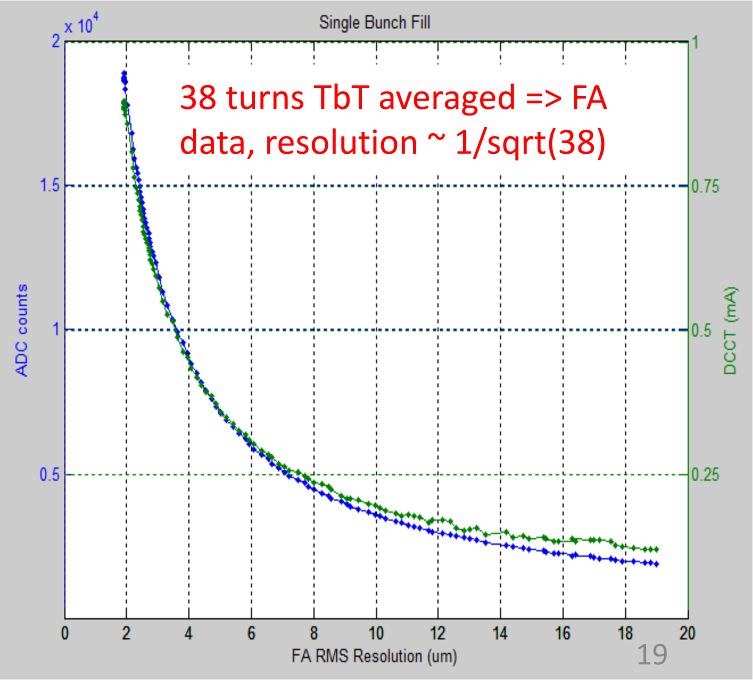
Button SUM signal corrected with button geometry, cable attenuations, and beam positions.

SR BPM – electronics resolution and timing



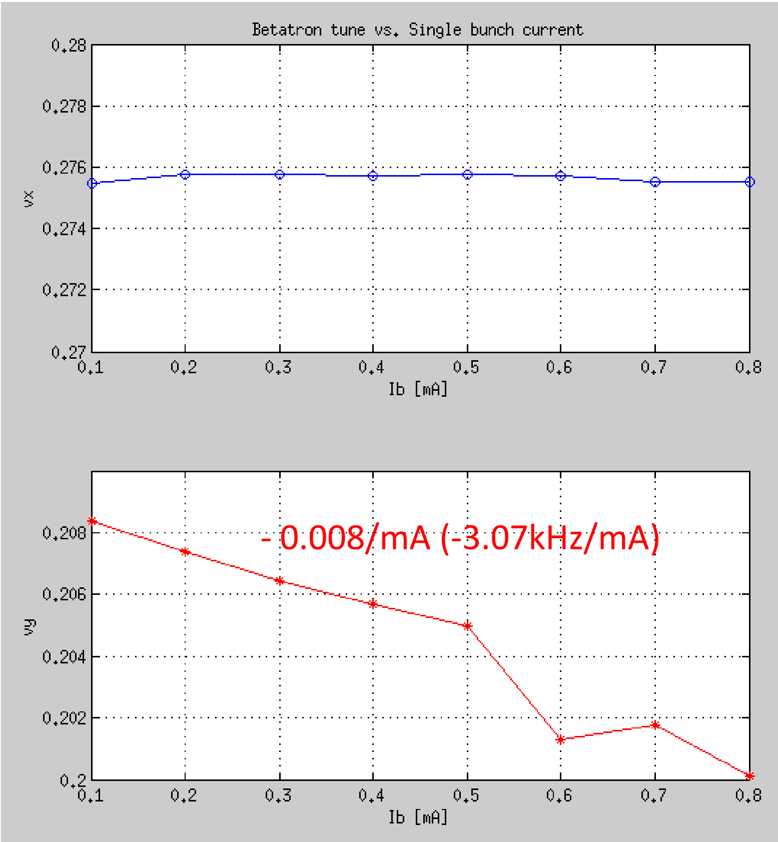




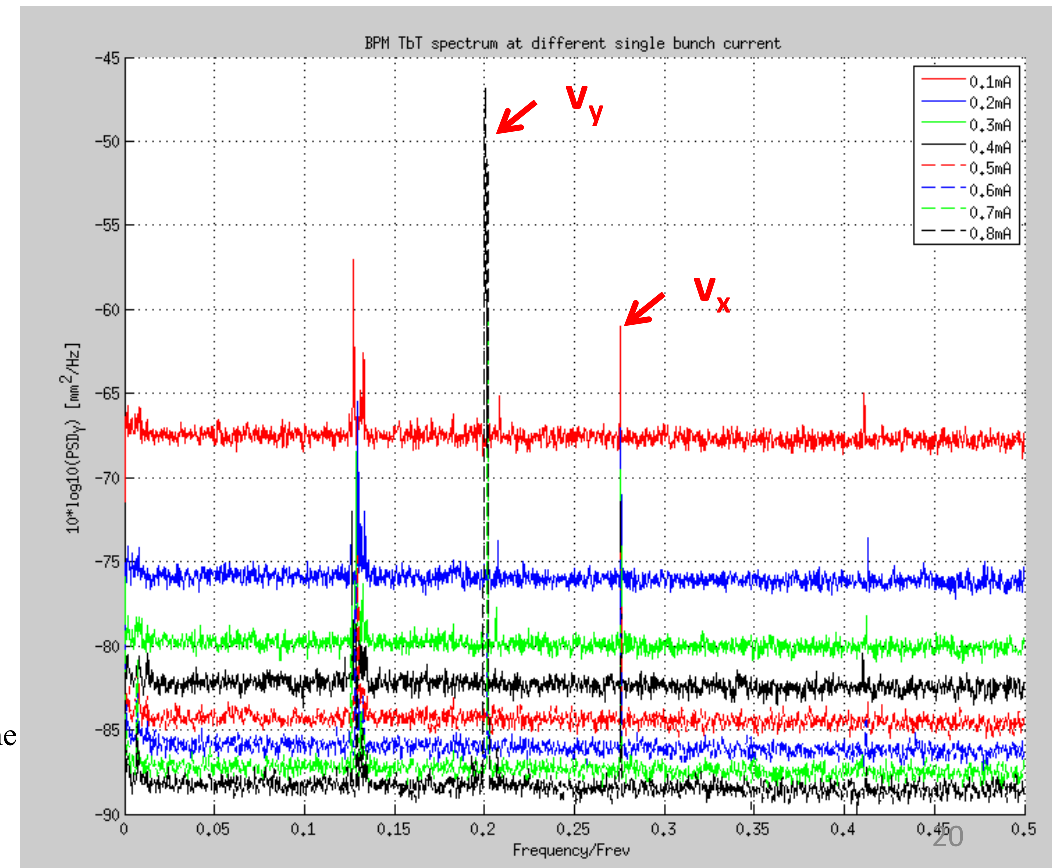


J. Mead, WEPD27

SR BPMs – TbT beam spectrum



Beam was kicked by injection kicker(s) and/or vertical pinger.
Record BPM TbT data at different single bunch current.
NFFT = 4096, Hanning window
Interpolated to get precise tunes
ν_x ~ 0.2755, don't change much at different current
ν_y ~ 0.205, decreasing at higher current
ν_s ~ 0.007, Vrf = 1.9 MV
Noise ~ 0.13



$$\Delta Q_\beta = \frac{I_b T_0}{4\pi E/e}\langle\beta\rangle k_{\perp total} = \frac{I_b T_0}{4\pi E/e}\sum_j \beta_j k_{\perp j}$$

T_0 is the ring revolution period

I_b is the single bunch current

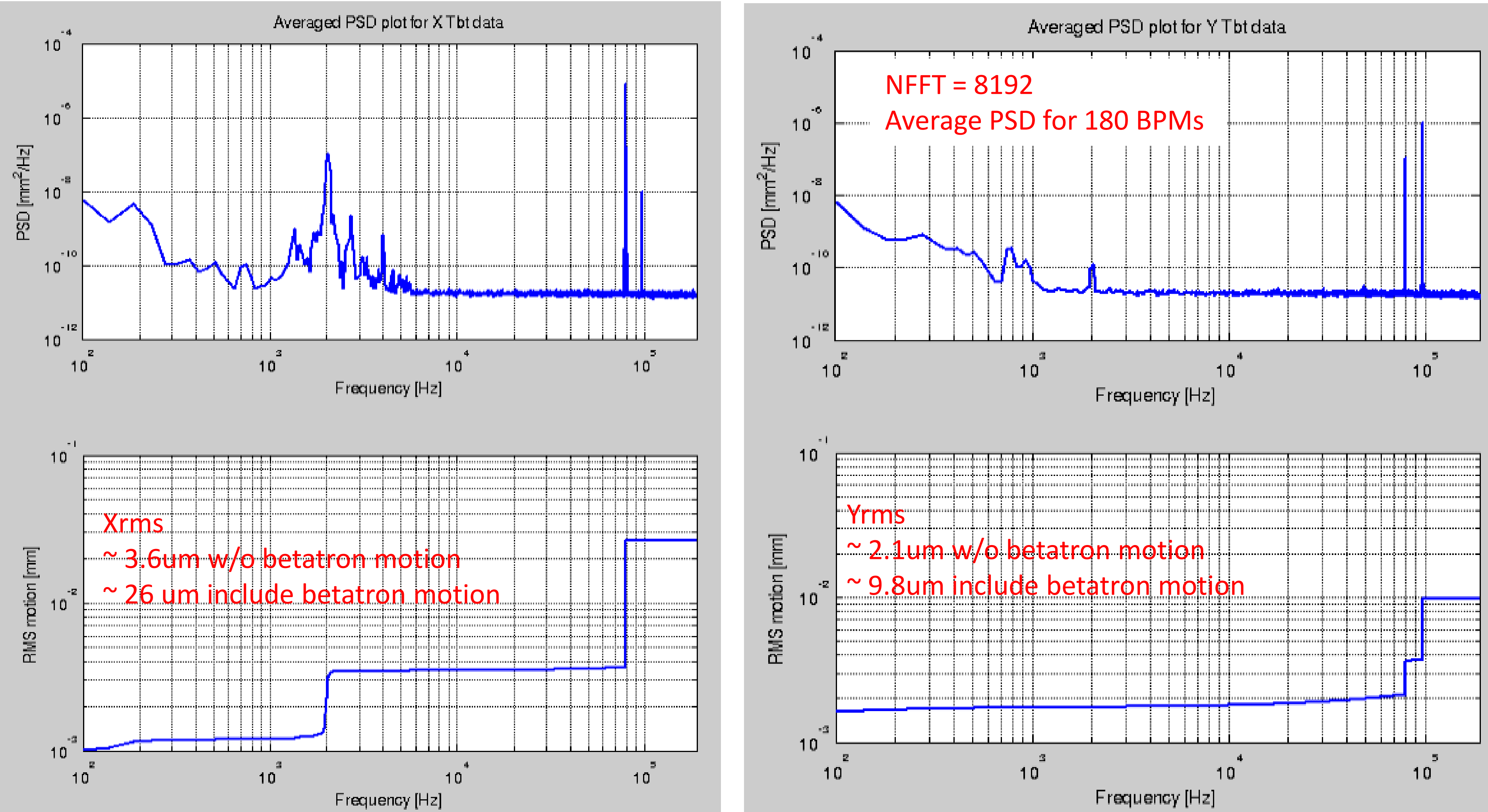
E is the beam energy

$\langle\beta\rangle$ is average beta-function, ~ 7.7m for NSLS2 vertical plane

We get $k_{\perp total} = \underline{14.8 kV/pC/m}$

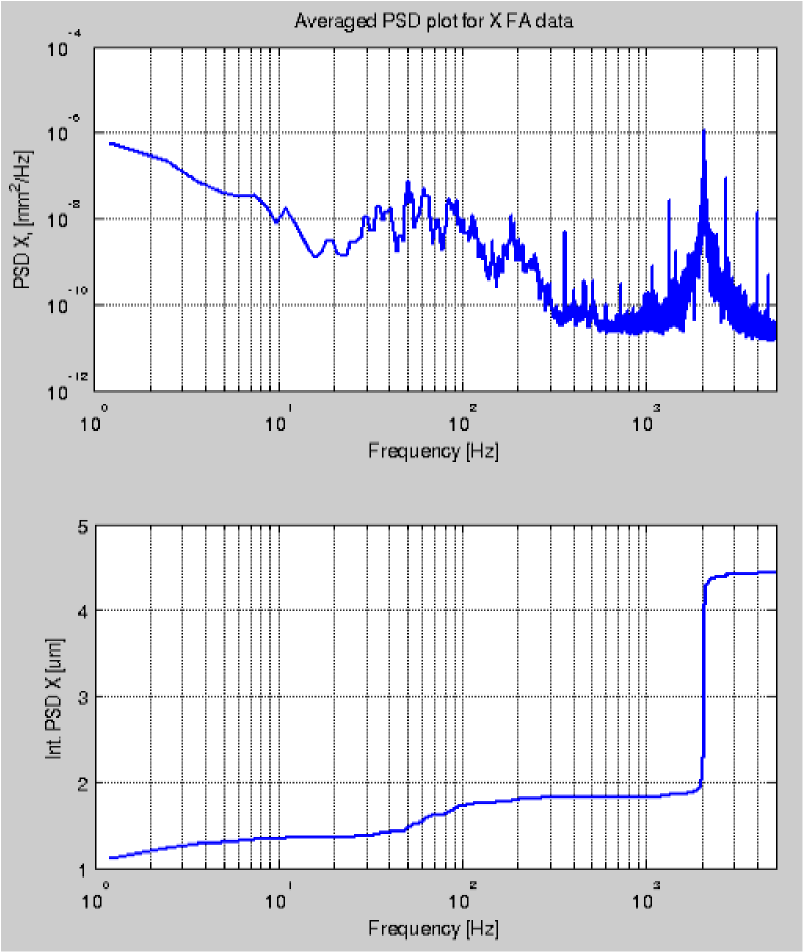
SR BPMs – beam spectrum

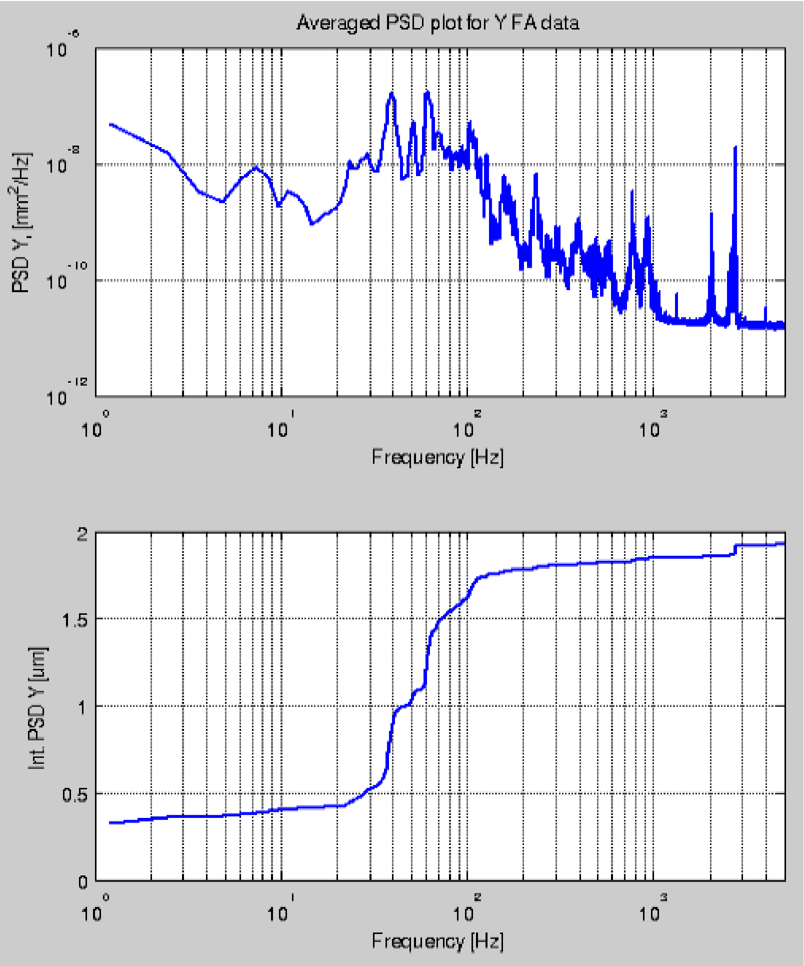
BPM TbT data from 2015-Jul-11, 17:44:21, 23mA store beam, BxB feedback OFF



10kHz FA data characterize the lower frequency (< kHz) beam motions

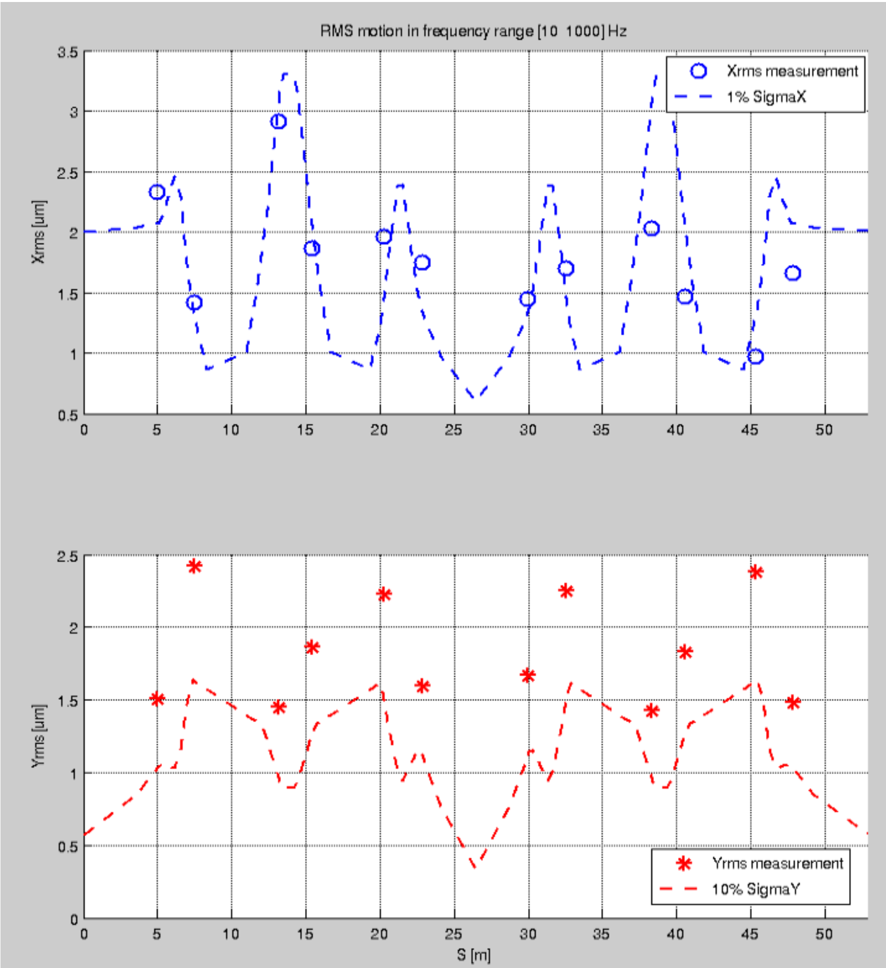
BPM FA data recorded at 20:43:43, Jul-11-2014
~ 44mA stored beam





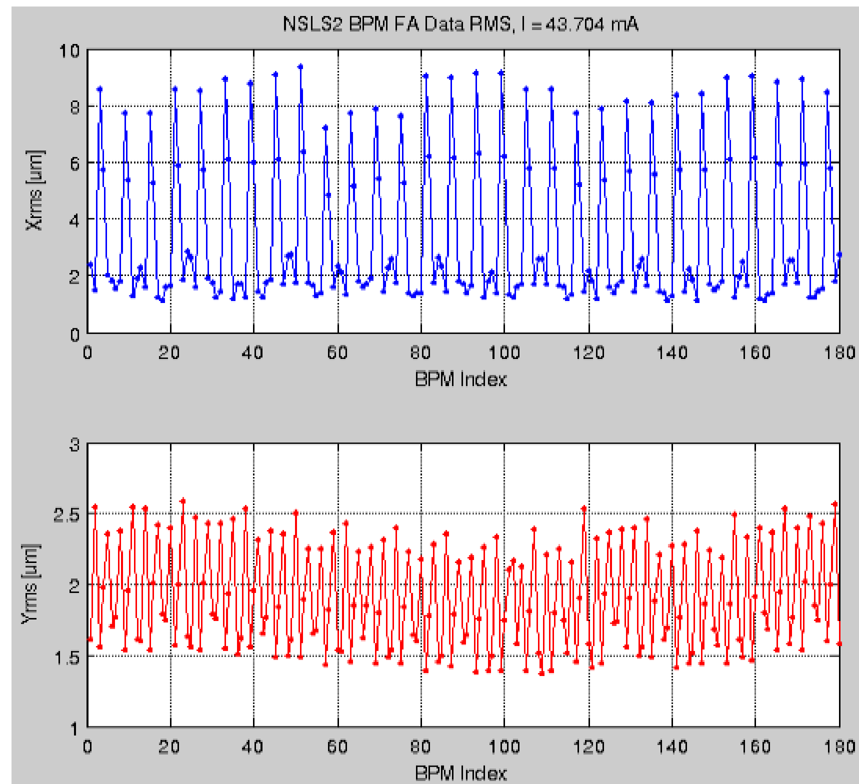
NFFT = 8192, PSD spectrum averaged for three blocks of FFT
~ 1.8 um RMS motion (< 1kHz) in both x/y

44mA 1040 bunches, FA data spectrum from all BPMs



[0, 5kHz] PSD integration
Xrms 6um contribution from energy jitter and dispersion, at BPM3. Assume 0.4m dispersion at BPM3, the energy jitter ~ 1.5e-5

This is corresponding to ~ 2.2 deg phase jitter of 1.2MV Vrf. 2.2deg@500MHz <=> 12 ps, this looks huge and should be visible on streak cameras dual sweep, will check.



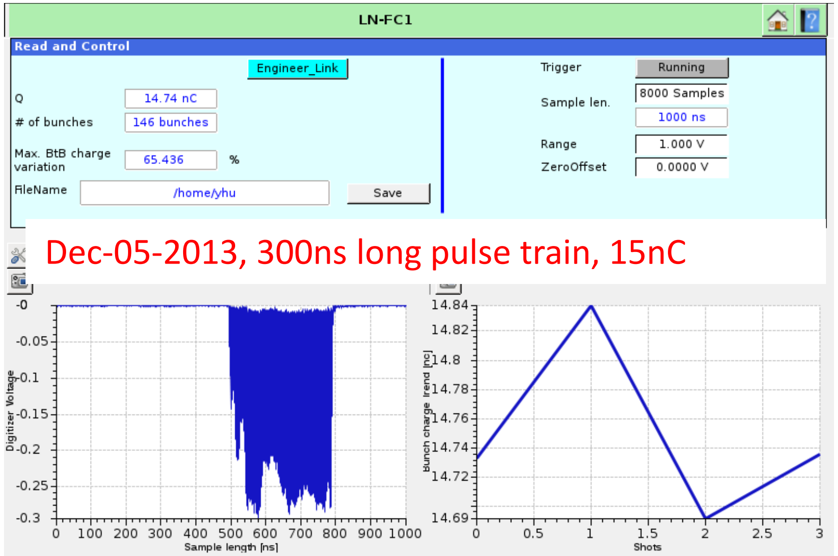
Xrms, Yrms integrated from psd in the range of [10,1000]Hz
Compare with model beam sizes

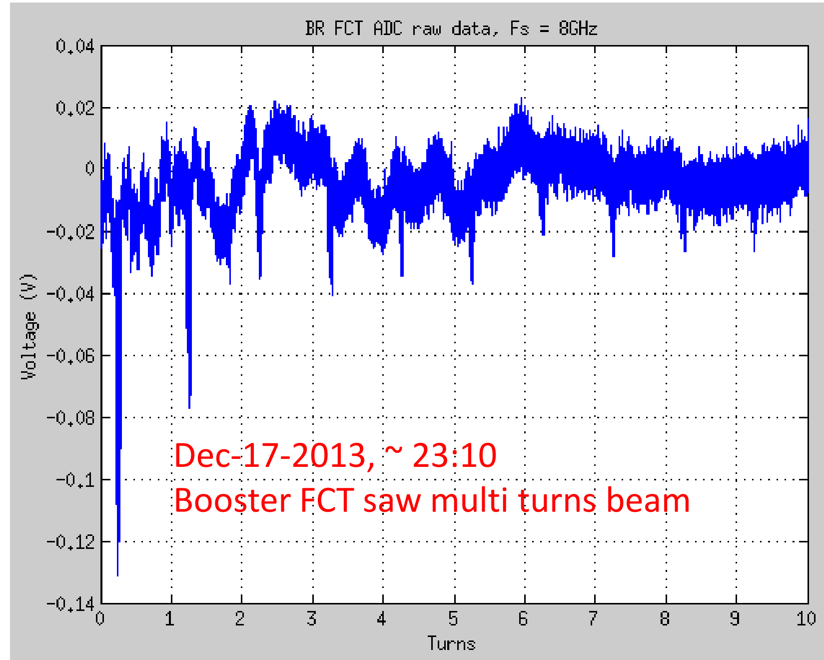
Average of 180 BPMs data we get:
mean(Xrms) = 1.7um
mean(Yrms) = 1.77 um

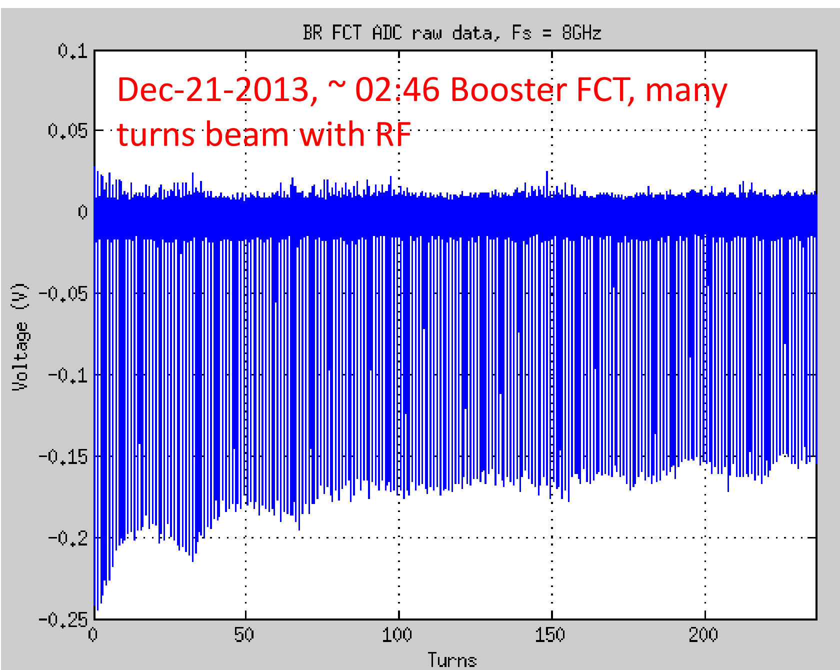
2. Current monitors

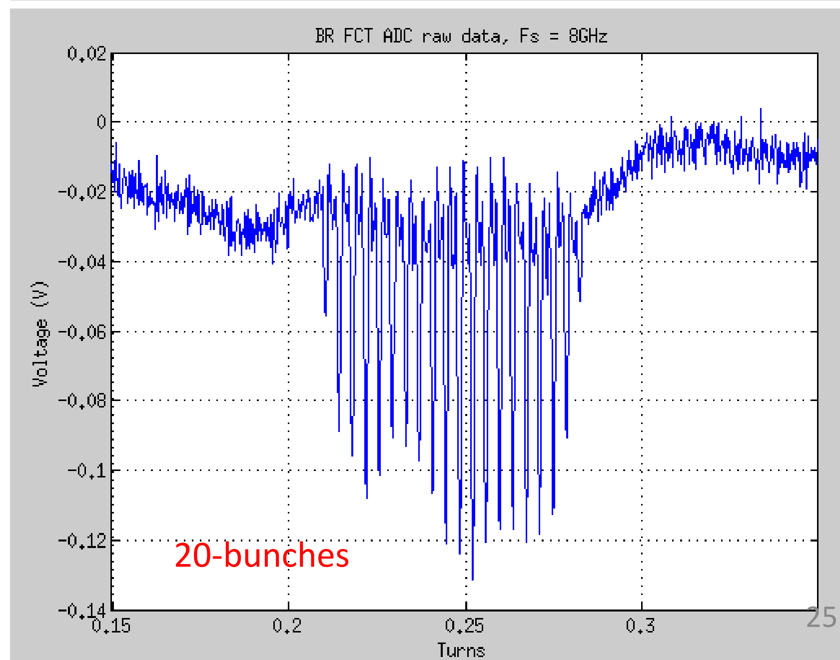
(Faraday cup, WCM, FCT, ICT, DCCT, FPM)

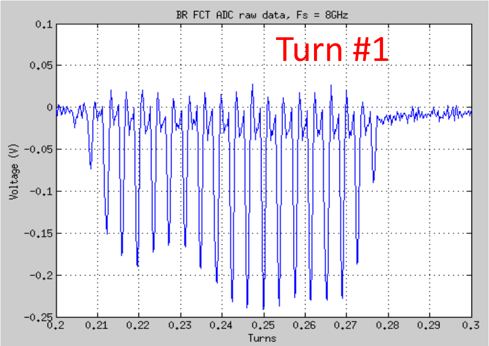
Current monitors - Faraday cup, FCT

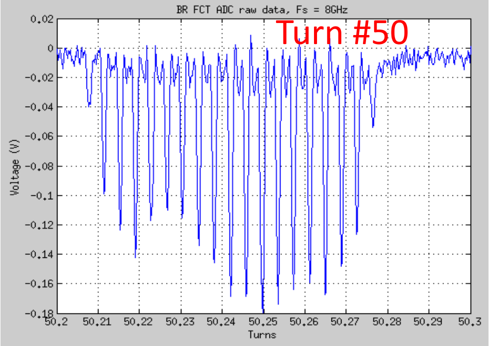


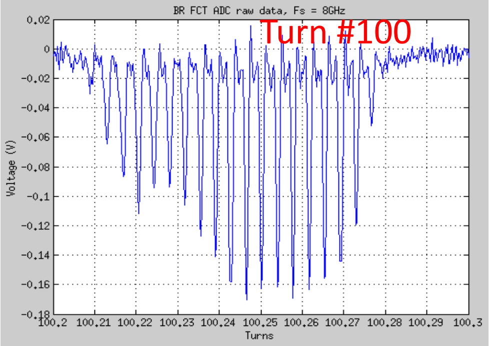


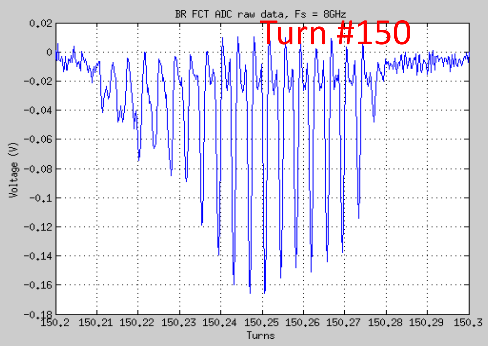


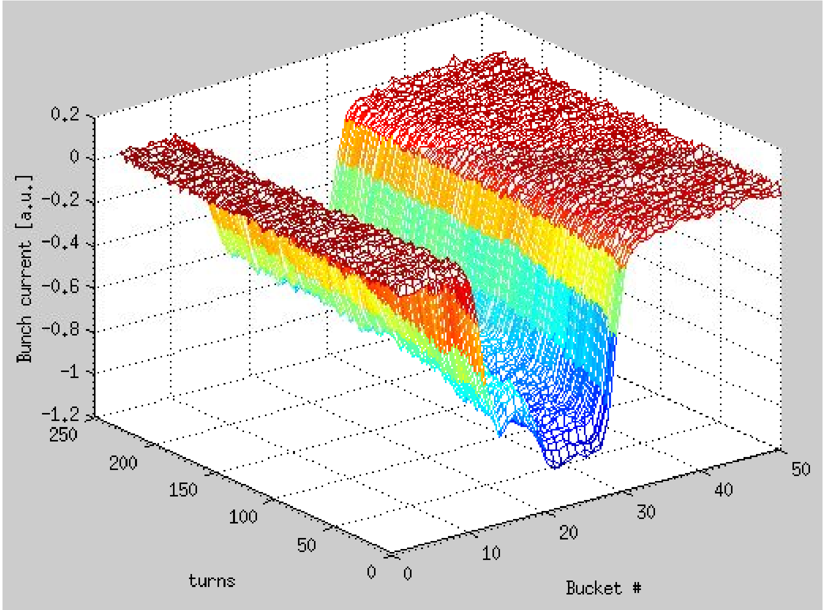


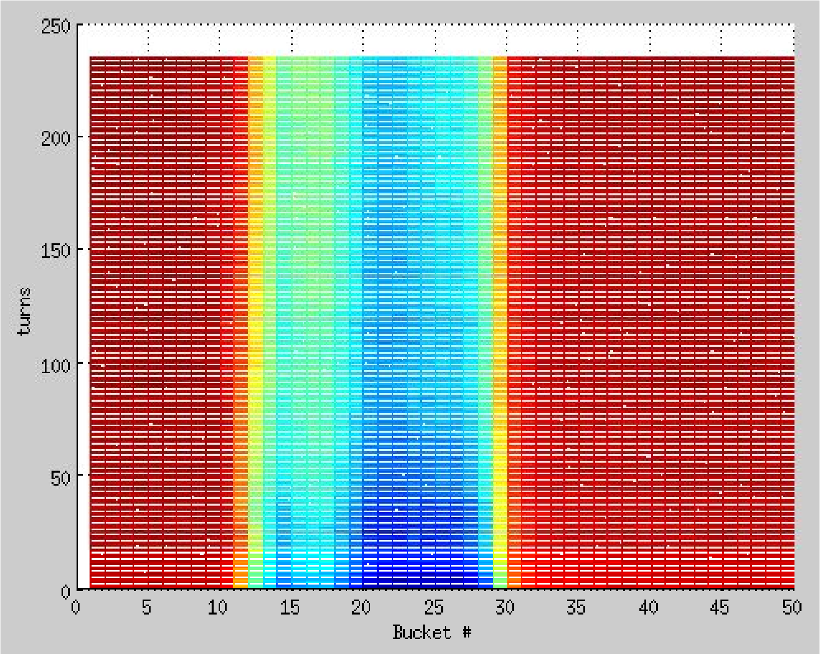

BR FCT ADC raw data, Fs = 8GHz
Turn #1
Voltage (V)
Turns


BR FCT ADC raw data, Fs = 8GHz
Turn #50
Voltage (V)
Turns

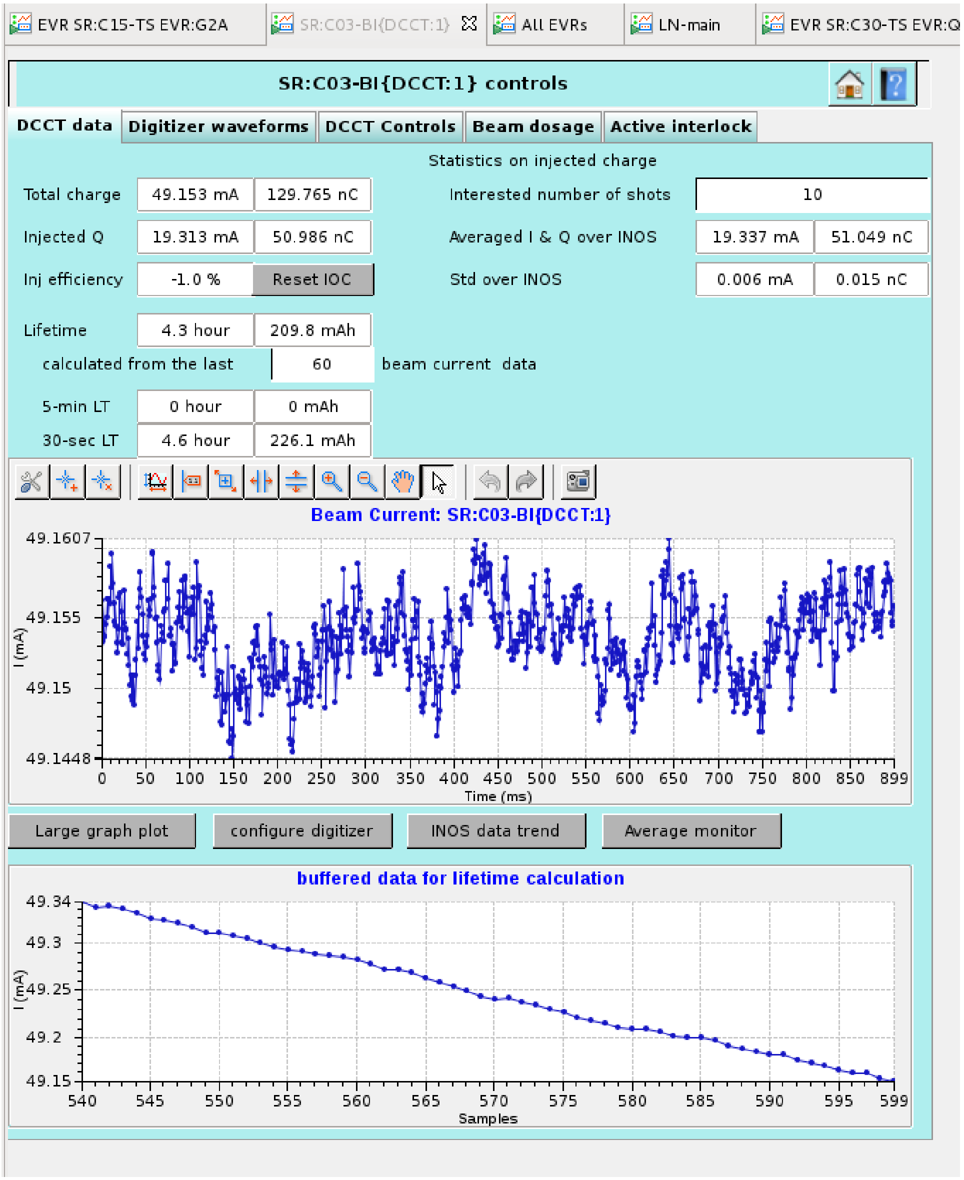

BR FCT ADC raw data, Fs = 8GHz
Turn #100
Voltage (V)
Turns


BR FCT ADC raw data, Fs = 8GHz
Turn #150
Voltage (V)
Turns


Bunch current [a.u.]
turns
Bucket #


turns
Bucket #

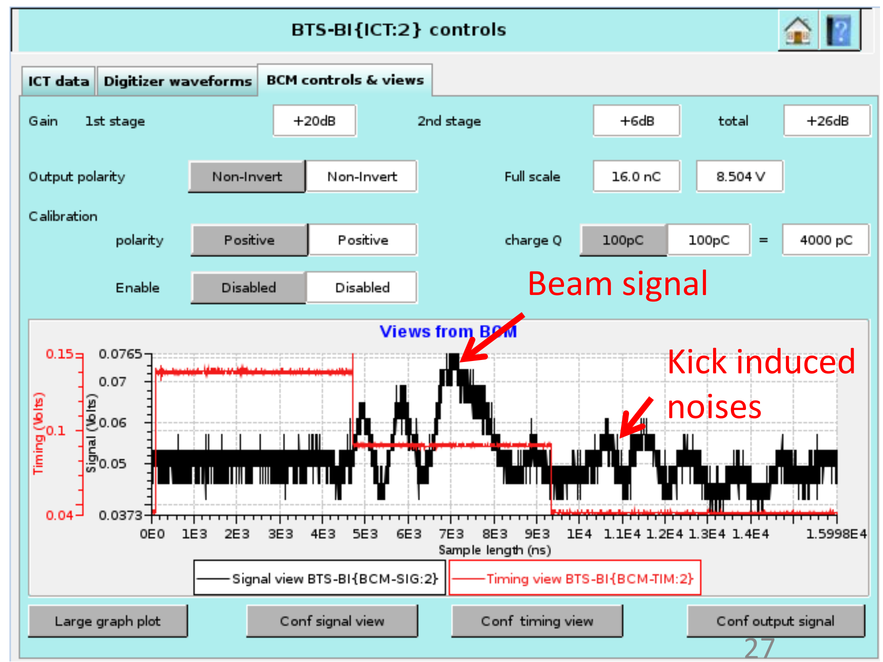
Current monitors – DCCT, ICT



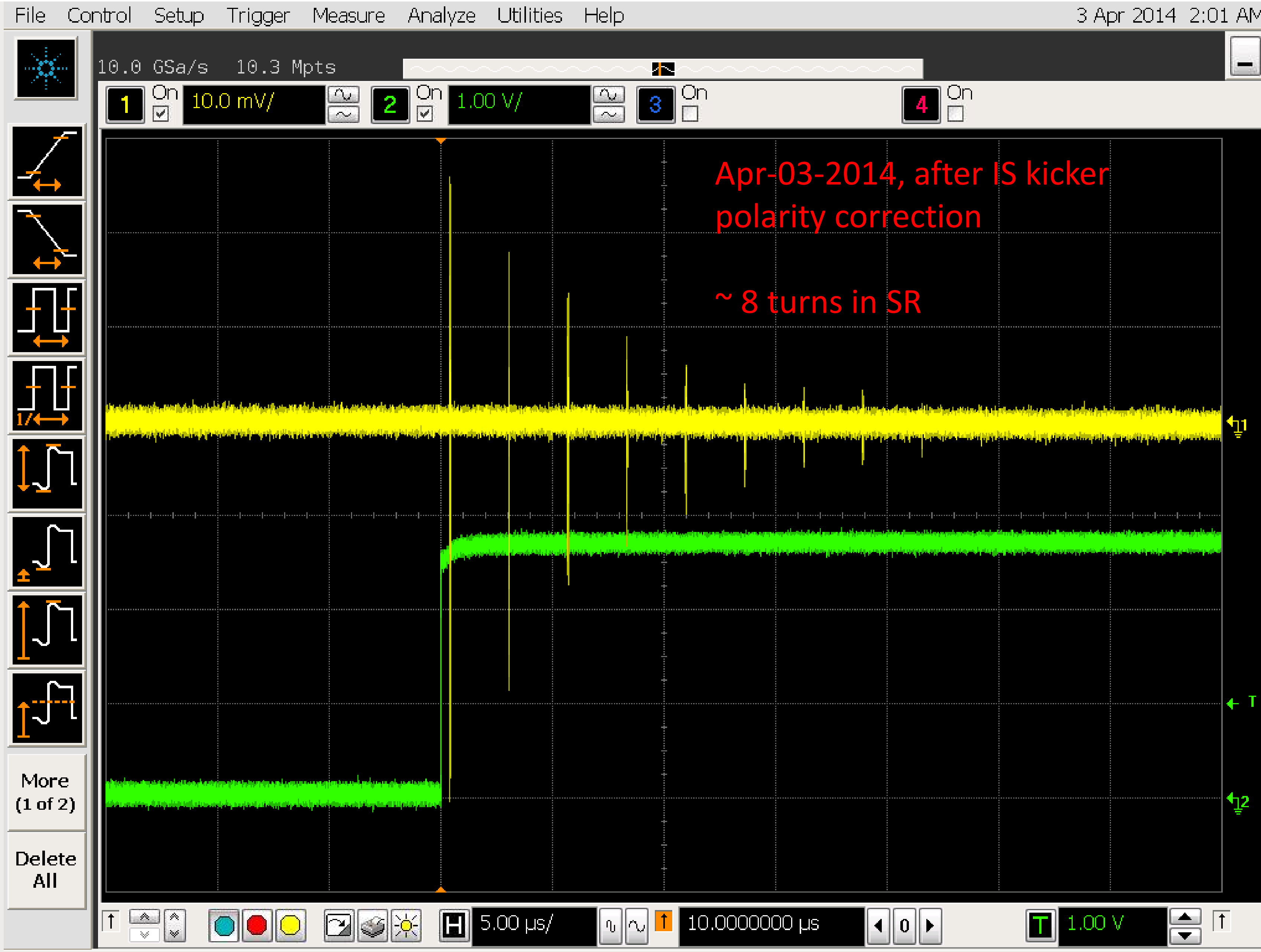
SR DCCT noise

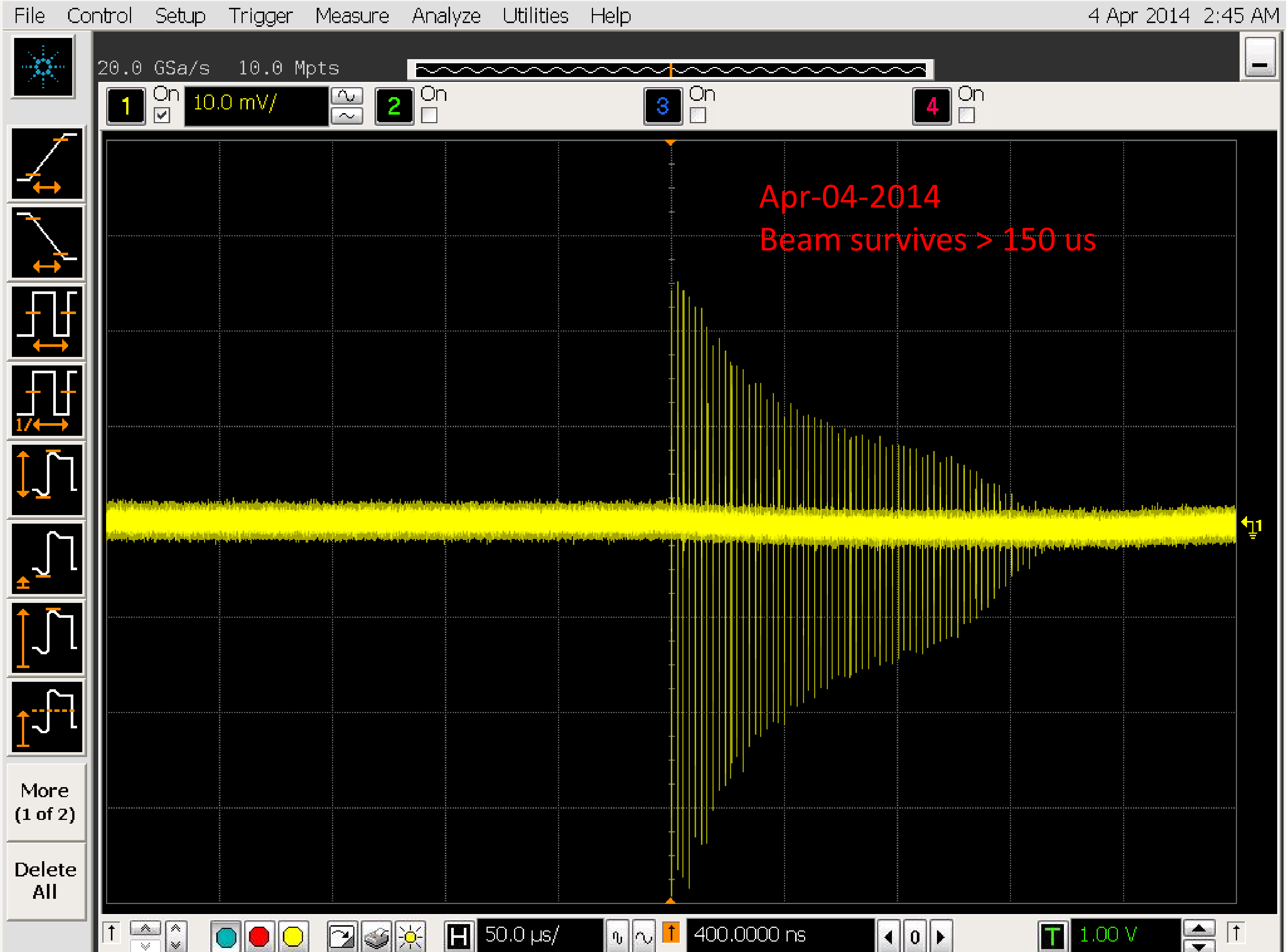
- SR DCCT noise was 40uA noises, hard to fit a good lifetime
- Suppressed to 3uA resolution by adding LPF and decreasing digitizer sampling rate
- Further improvement possible to < 1uA

Mar-27-2014, BtS ICT sees the beam signal and kicker noise, at BCM signal view.

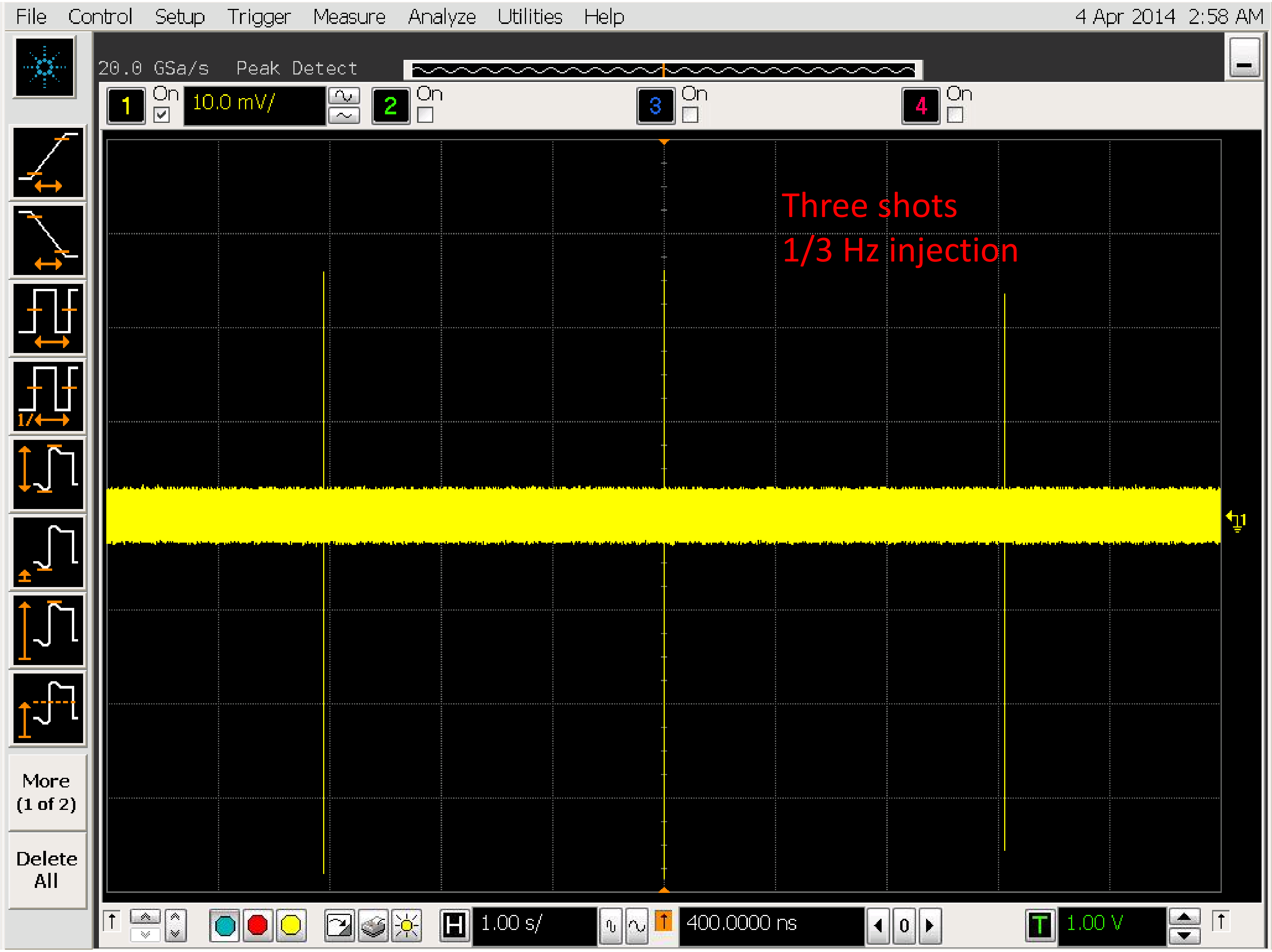


SR Filling pattern monitor – high sampling rate scope

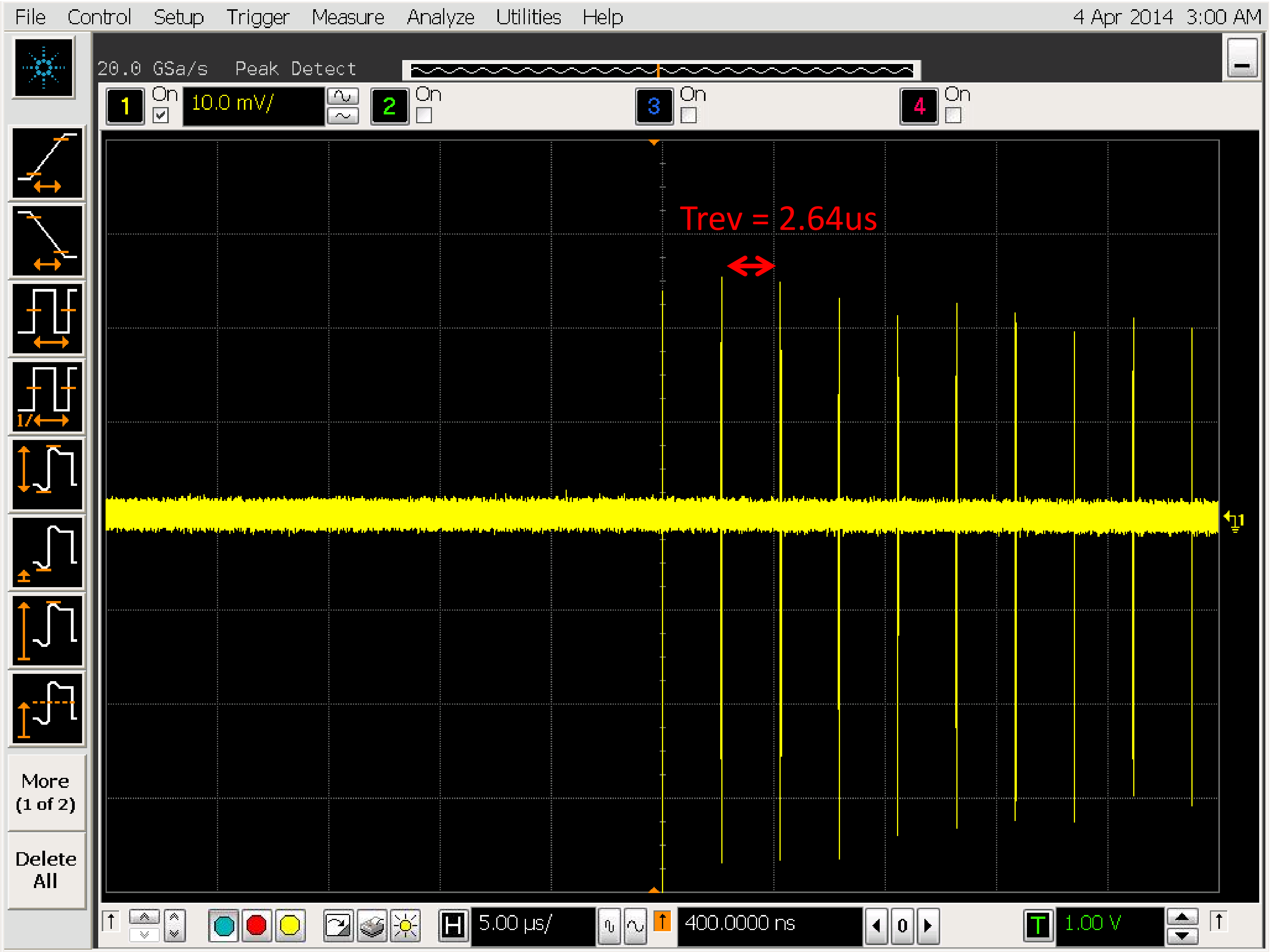


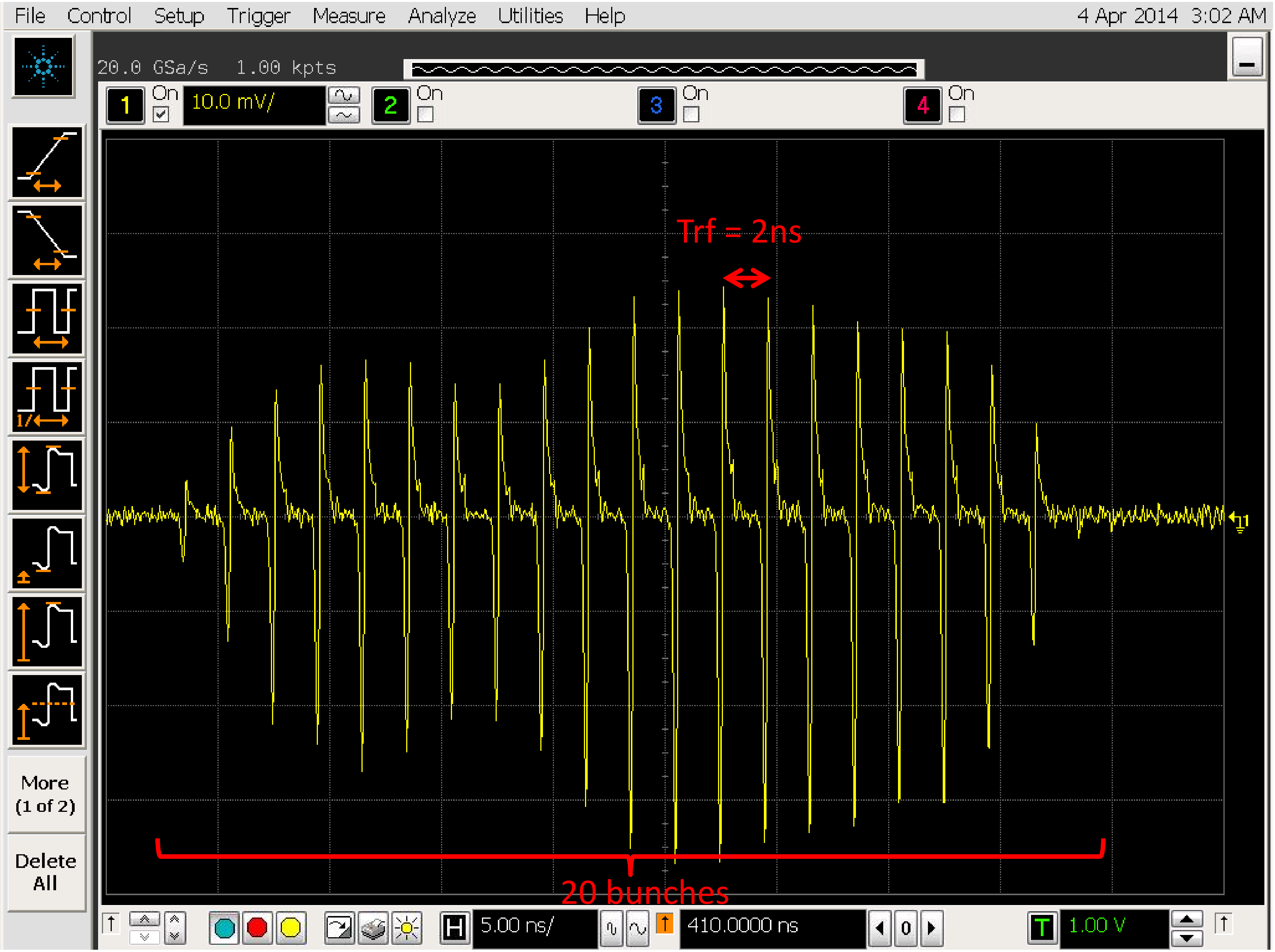


File Control Setup Trigger Measure Analyze Utilities Help
4 Apr 2014 2:45 AM
20.0 GSa/s 10.0 Mpts
1 On 10.0 mV/
2 On
3 On
4 On
Apr-04-2014
Beam survives > 150 us
More (1 of 2)
Delete All
50.0 µs/
400.0000 ns
1.00 V

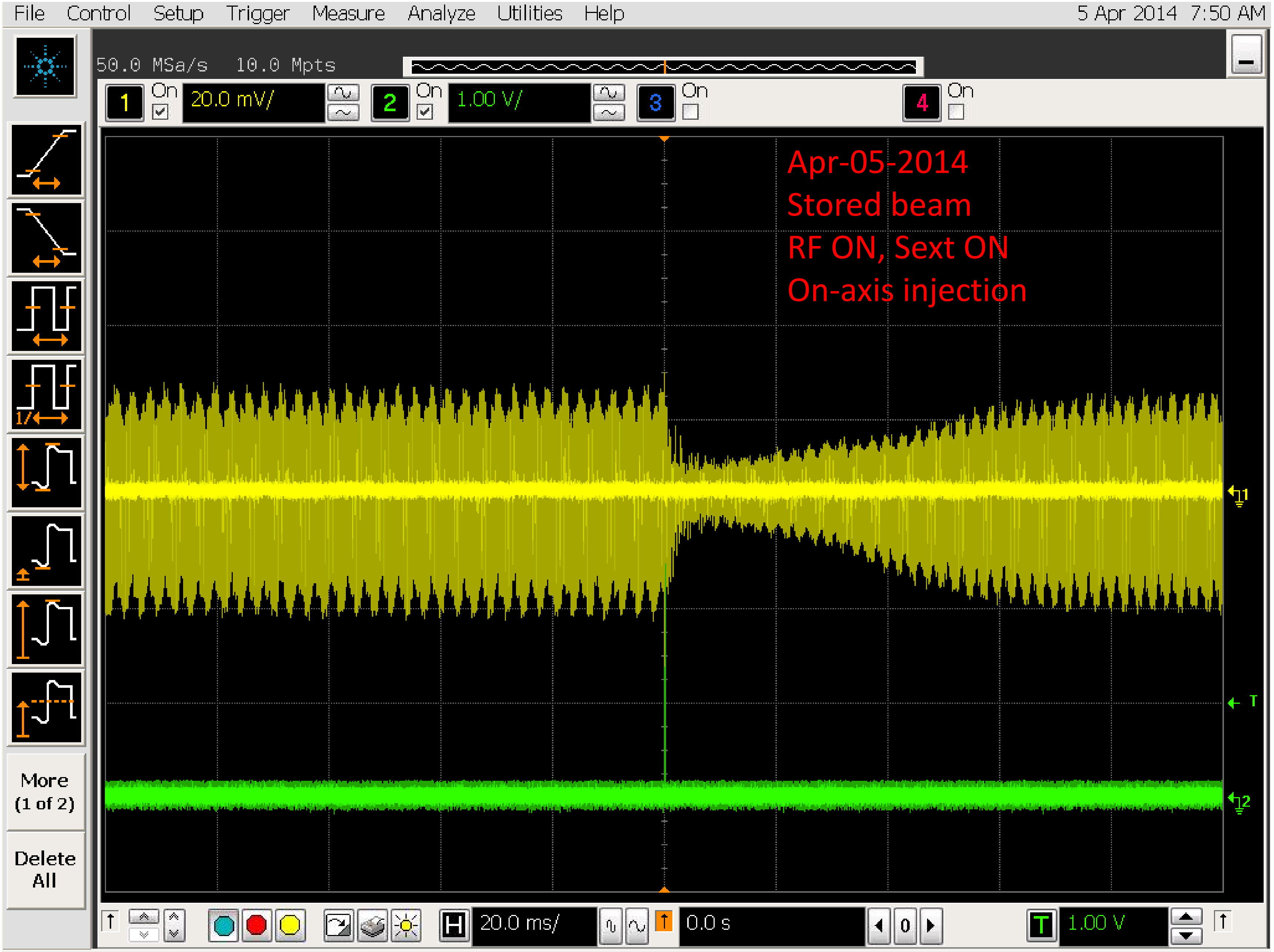


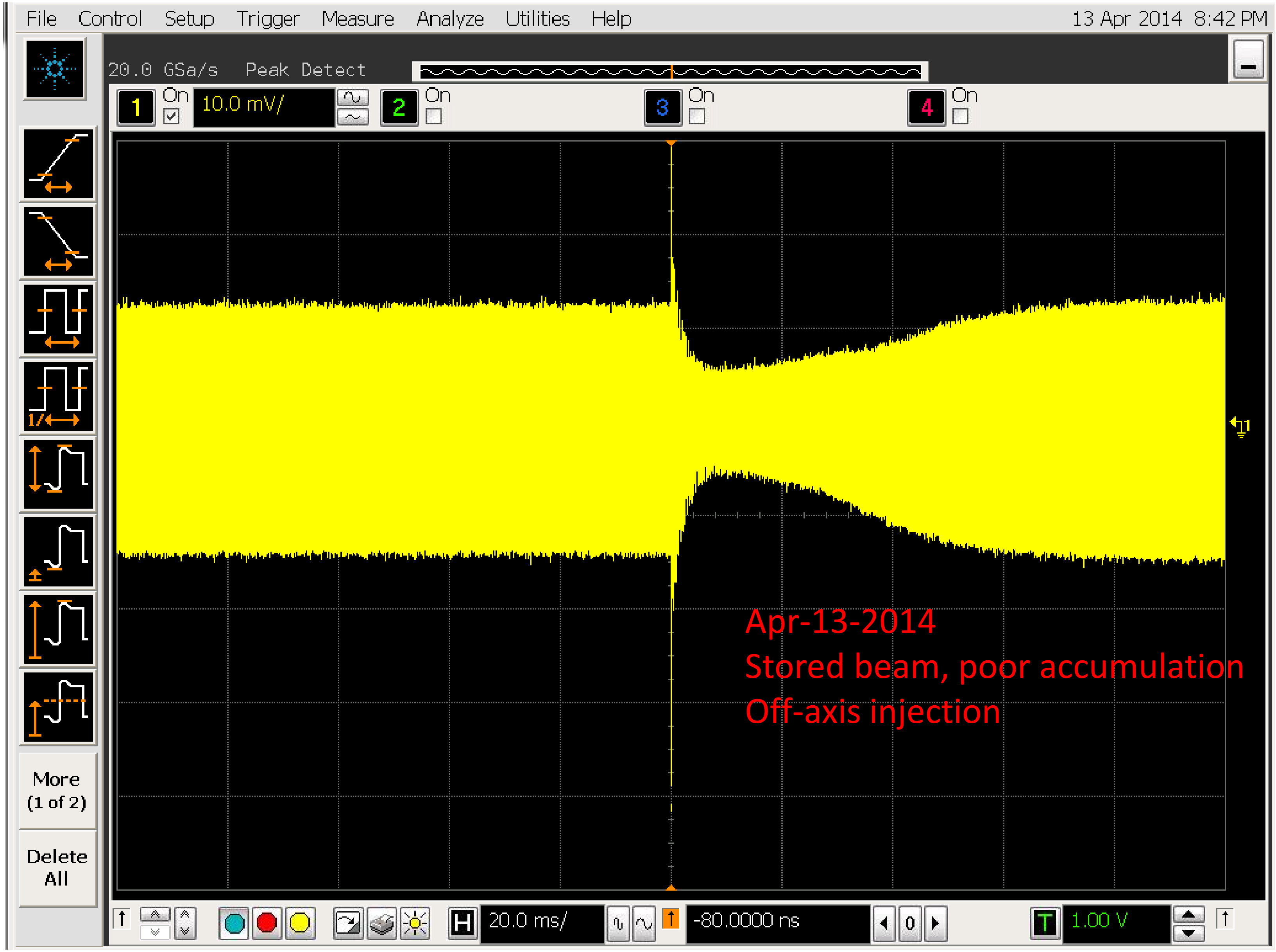
File Control Setup Trigger Measure Analyze Utilities Help
4 Apr 2014 2:58 AM
20.0 GSa/s Peak Detect
1 On 10.0 mV/
2 On
3 On
4 On
Three shots
1/3 Hz injection
More (1 of 2)
Delete All
H 1.00 s/
400.0000 ns
0
T 1.00 V

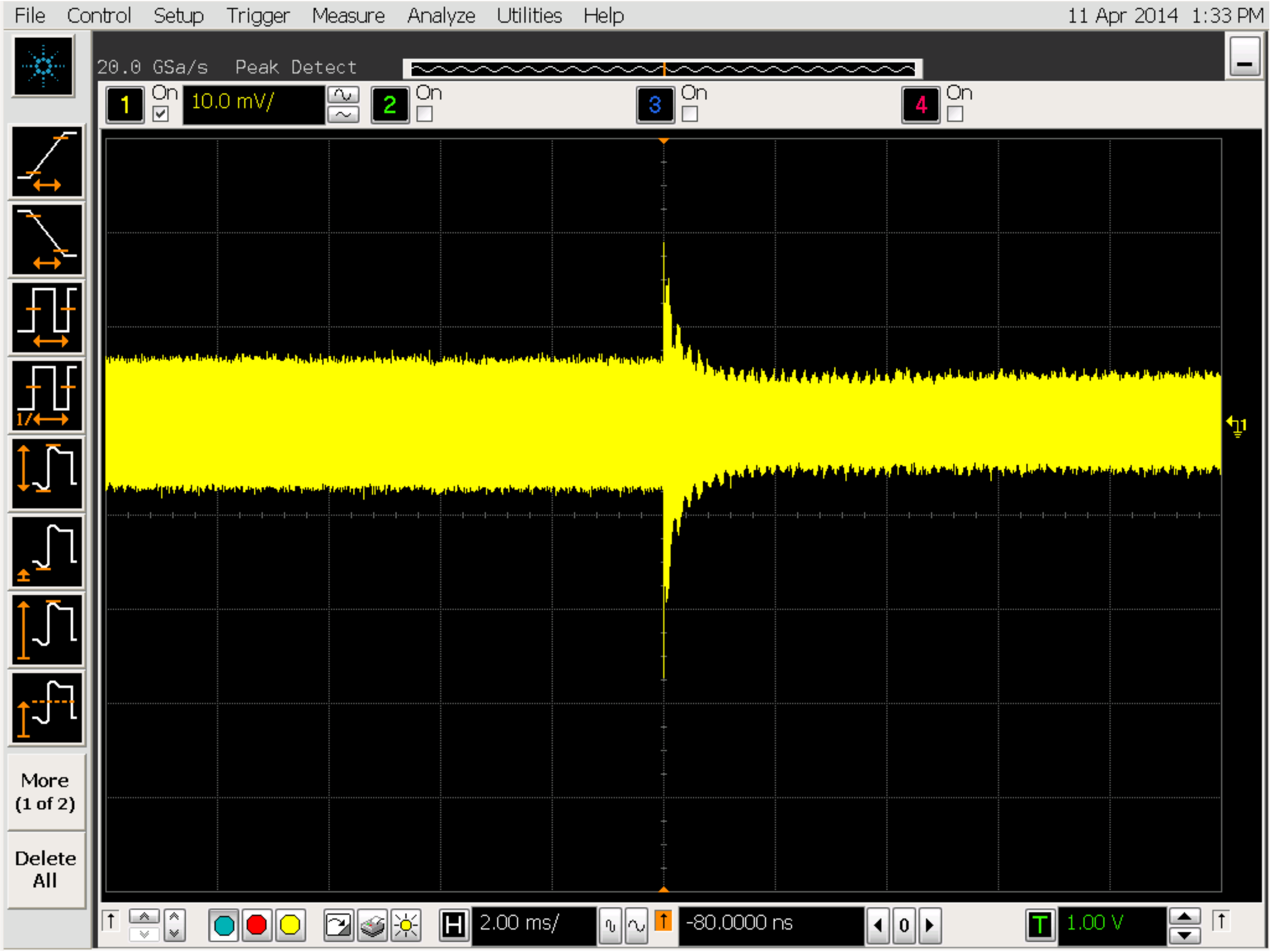

File Control Setup Trigger Measure Analyze Utilities Help
4 Apr 2014 3:00 AM
20.0 GSa/s Peak Detect
1 On 10.0 mV/
2 On
3 On
4 On
Trev = 2.64us
More (1 of 2)
Delete All
H 5.00 µs/
400.0000 ns
T 1.00 V



gun pulse width 40ns

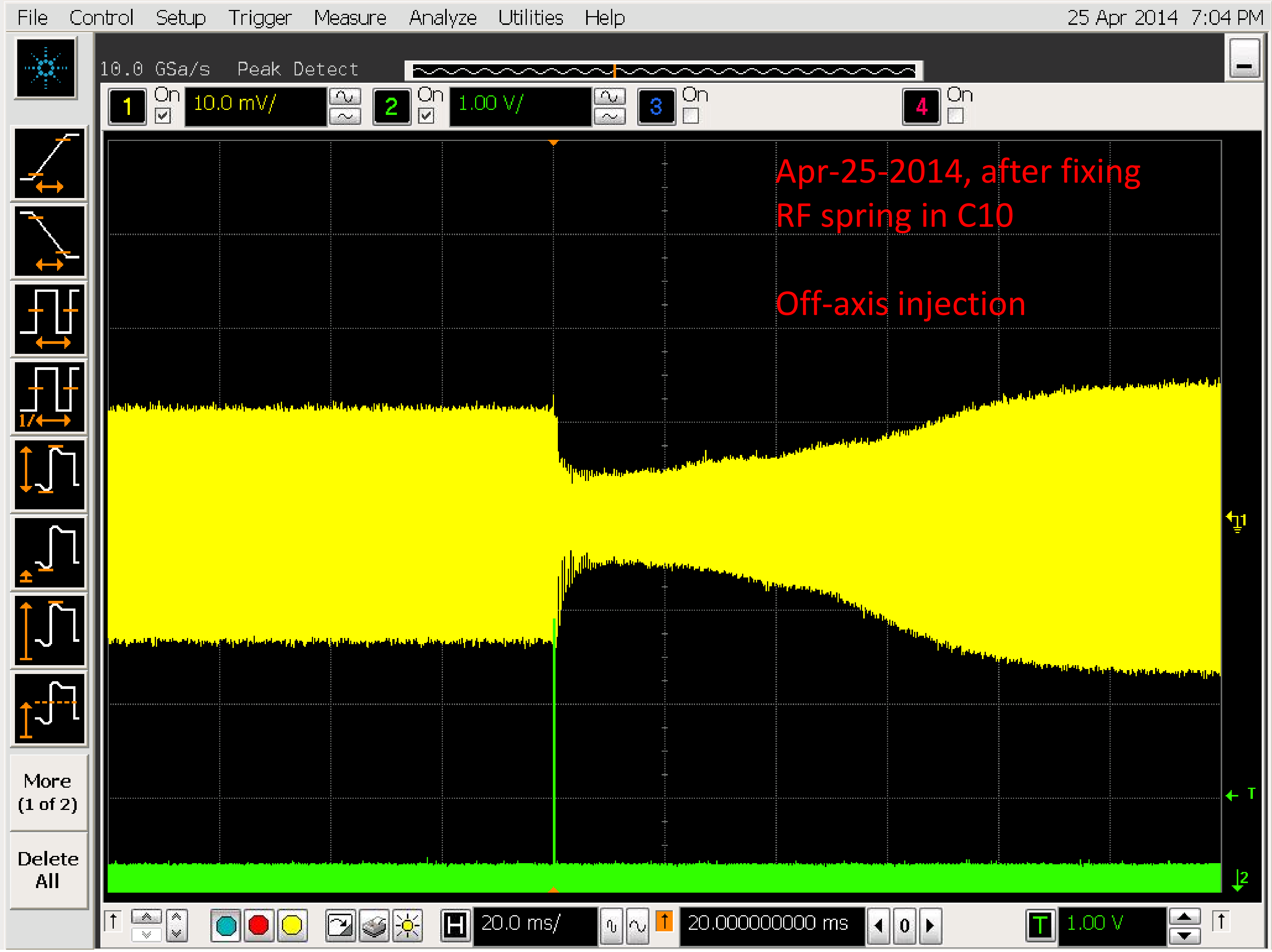

File Control Setup Trigger Measure Analyze Utilities Help
5 Apr 2014 7:50 AM
50.0 MSa/s 10.0 Mpts
1 On 20.0 mV/
2 On 1.00 V/
3 On
4 On
Apr-05-2014
Stored beam
RF ON, Sext ON
On-axis injection
More (1 of 2)
Delete All
H 20.0 ms/
0.0 s
T 1.00 V

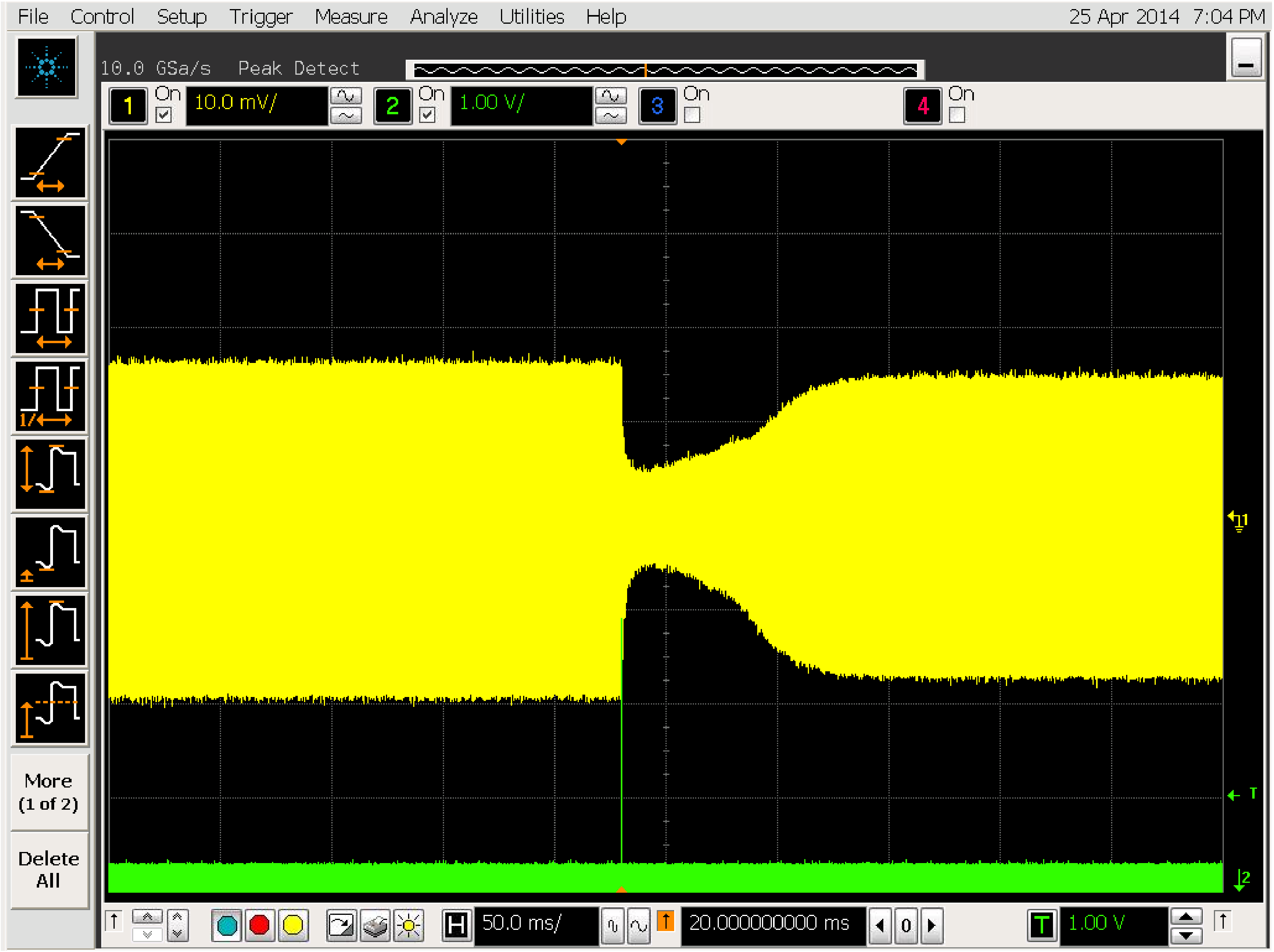

File Control Setup Trigger Measure Analyze Utilities Help
13 Apr 2014 8:42 PM
20.0 GSa/s Peak Detect
10.0 mV/
More (1 of 2)
Delete All
20.0 ms/
-80.0000 ns
1.00 V
Apr-13-2014
Stored beam, poor accumulation
Off-axis injection



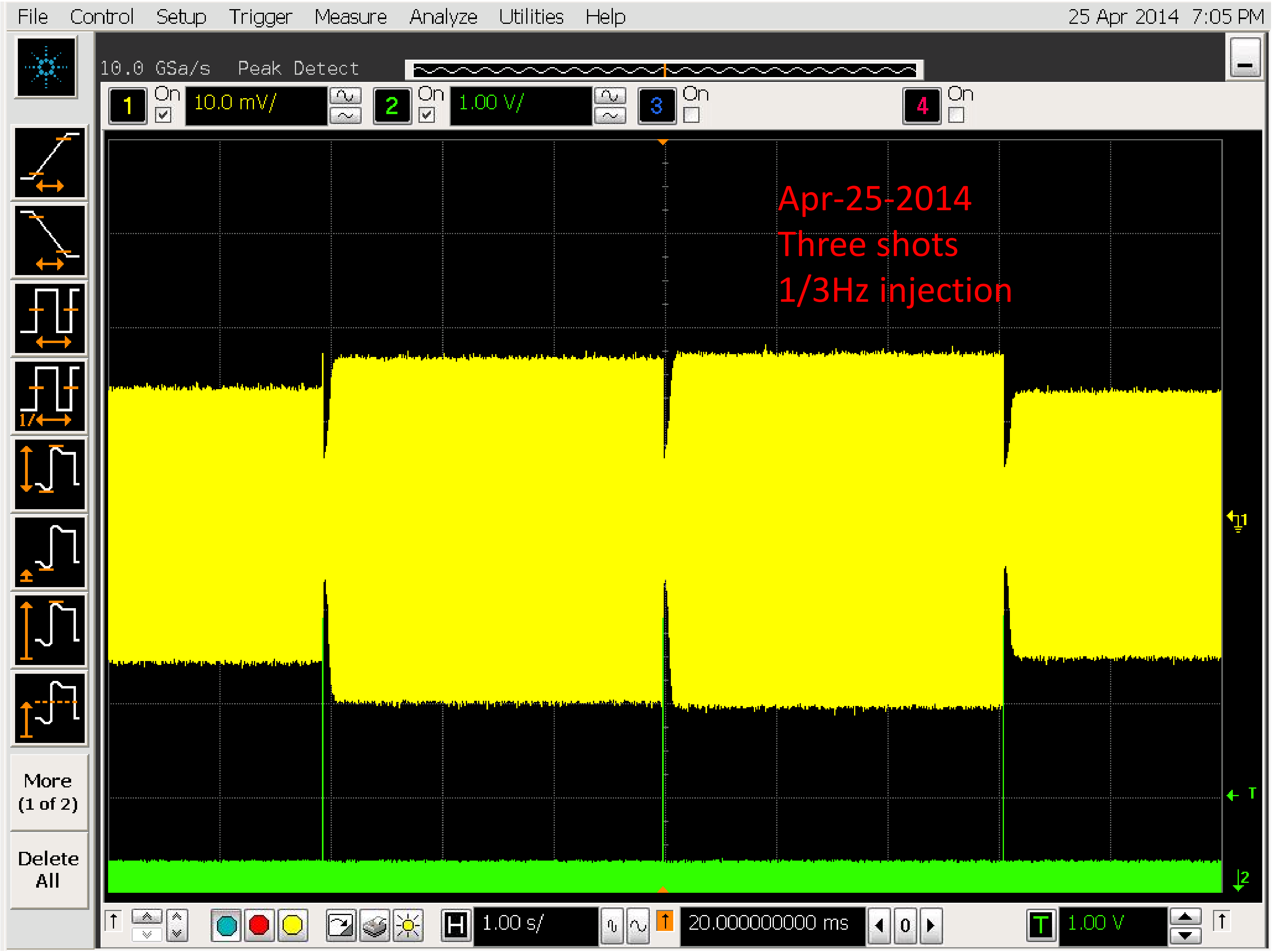
Captured on Apr-11, after Booster energy and SR RF phase adjusted, didn't see the dip on BPM raw button SUM signal.

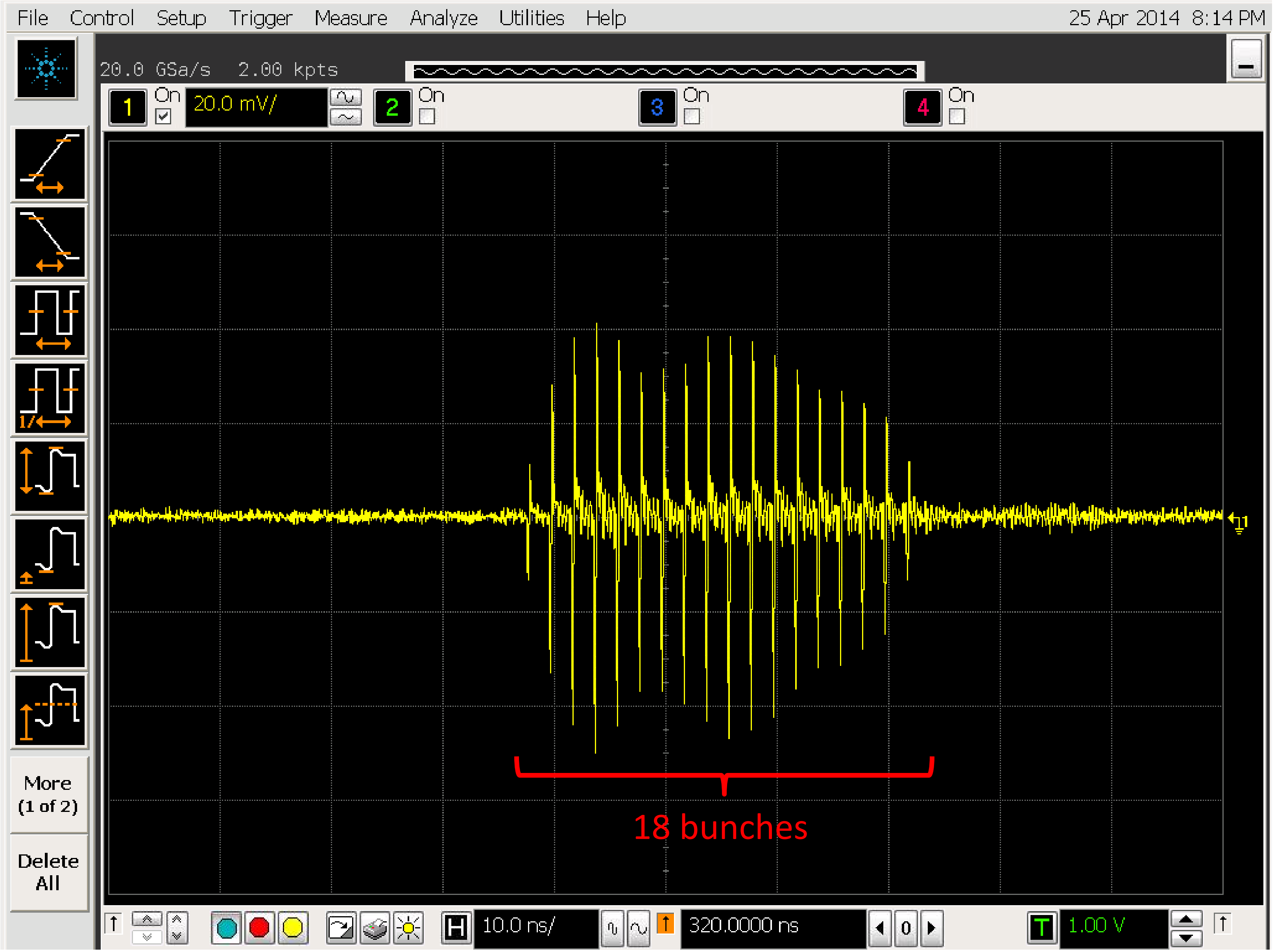
The reason we saw dip is because: longitudinal large oscillation filament => effective bunch length increase => SUM signal decrease. After radiation damping, bunch length decrease => SUM signal recovered.


File Control Setup Trigger Measure Analyze Utilities Help
25 Apr 2014 7:04 PM
10.0 GSa/s Peak Detect
1 On 10.0 mV/
2 On 1.00 V/
3 On
4 On
Apr-25-2014, after fixing
RF spring in C10
Off-axis injection
More (1 of 2)
Delete All
20.0 ms/
20.0000000000 ms
1.00 V

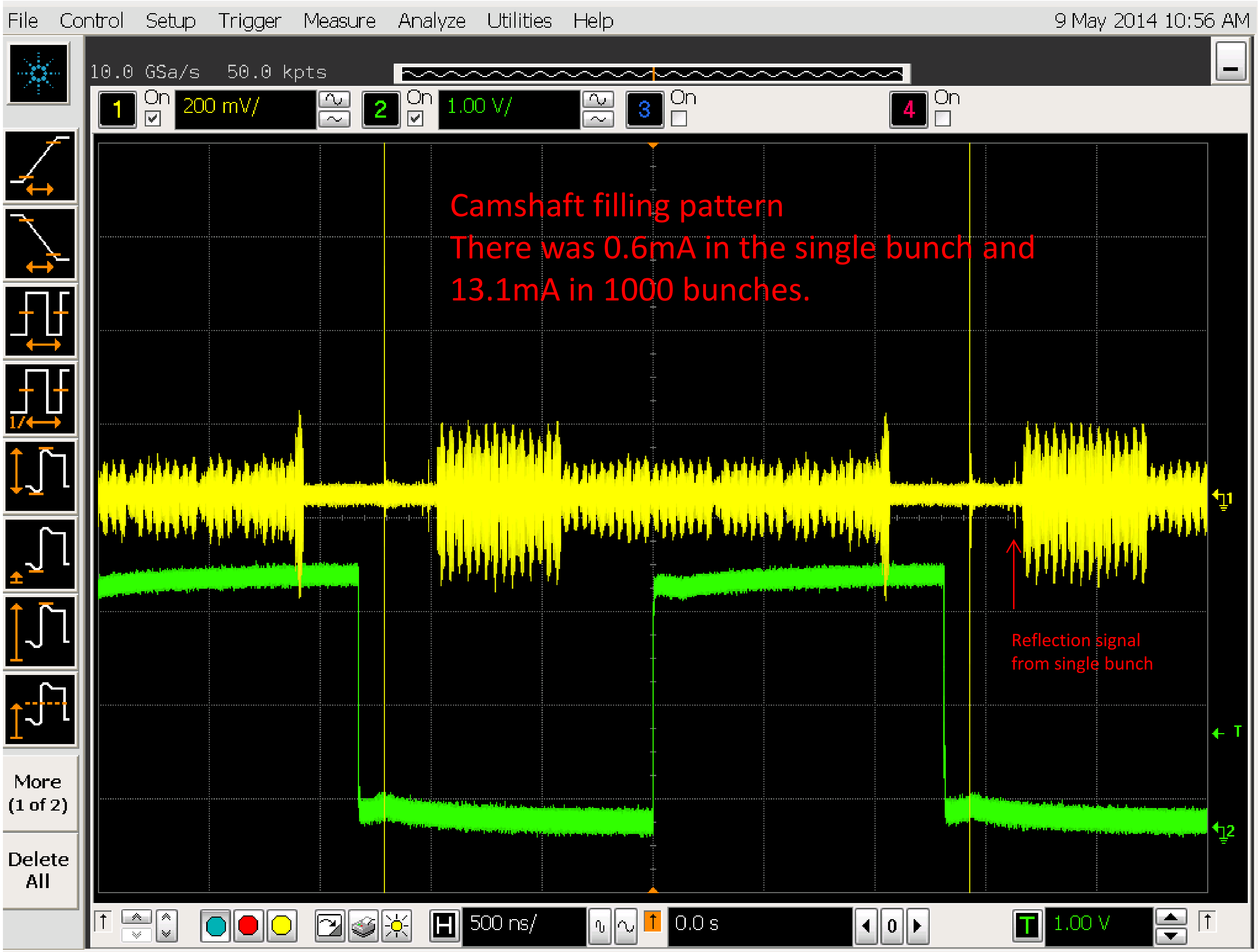


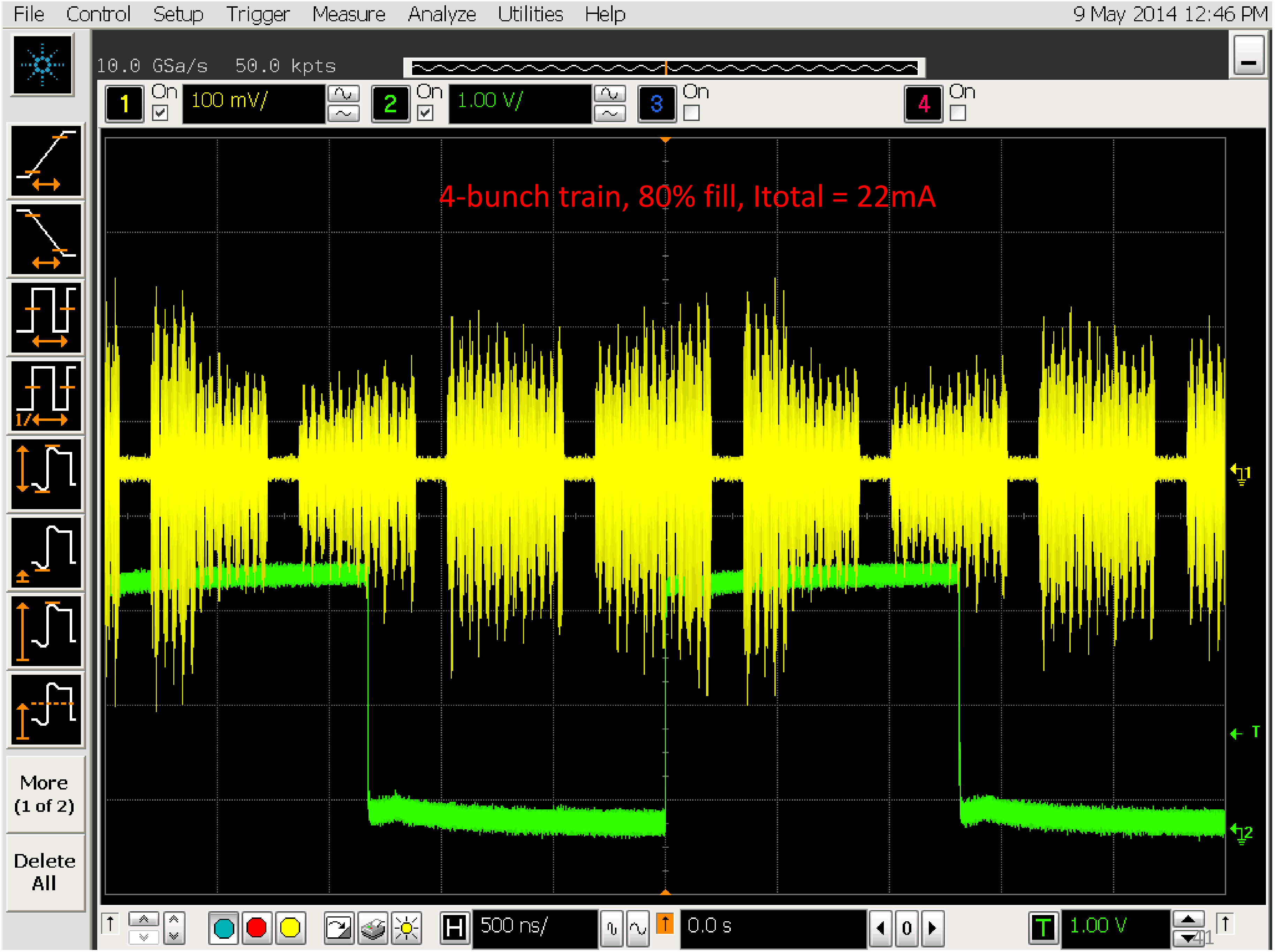
File Control Setup Trigger Measure Analyze Utilities Help
25 Apr 2014 7:04 PM
10.0 GSa/s Peak Detect
1 On 10.0 mV/
2 On 1.00 V/
3 On
4 On
More (1 of 2)
Delete All
H 50.0 ms/
20.000000000 ms
0
T 1.00 V

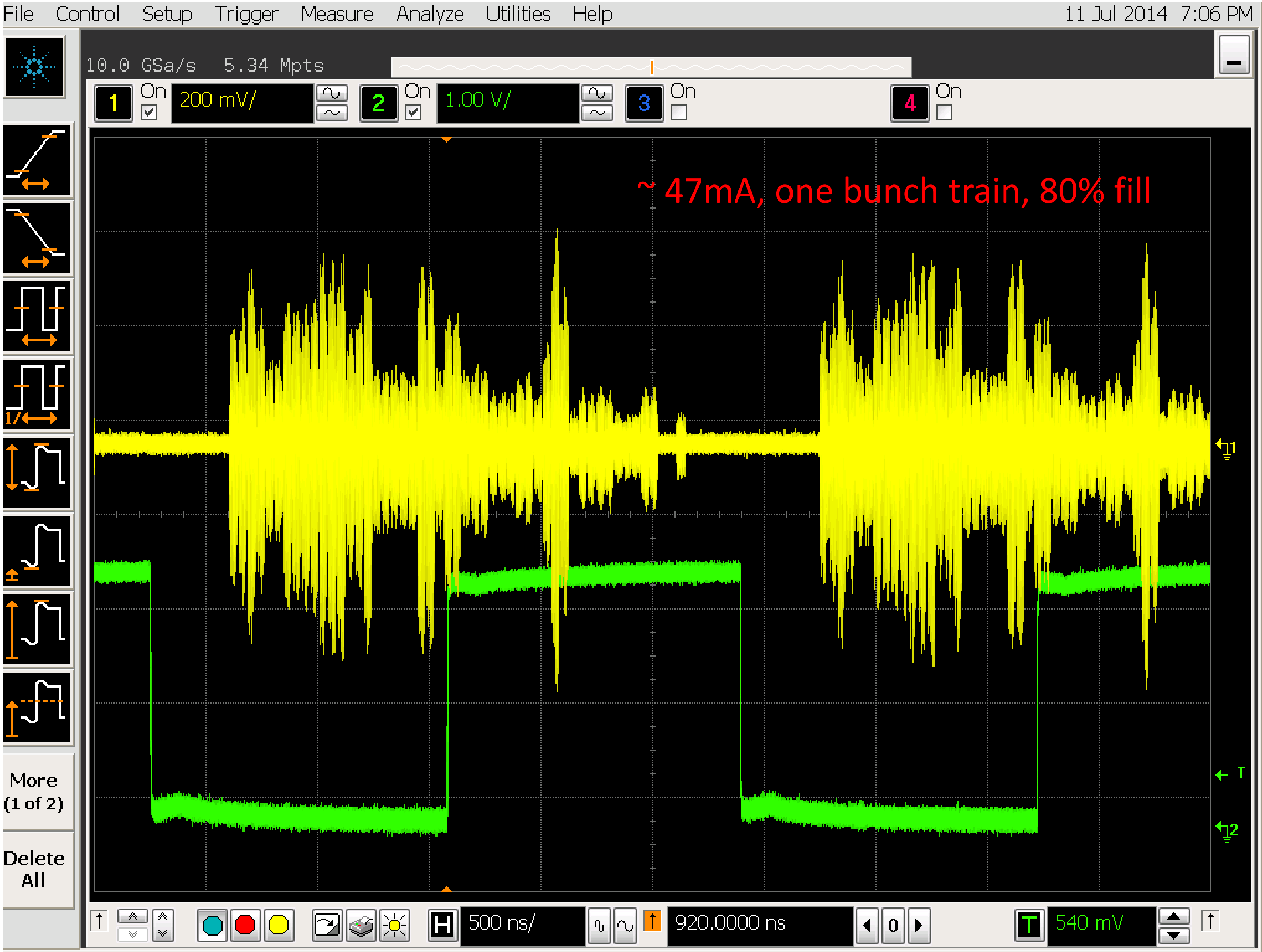

File Control Setup Trigger Measure Analyze Utilities Help
25 Apr 2014 7:05 PM
10.0 GSa/s Peak Detect
1 On 10.0 mV/
2 On 1.00 V/
3 On
4 On
Apr-25-2014
Three shots
1/3Hz injection
More (1 of 2)
Delete All
1.00 s/
20.000000000 ms
1.00 V



Stored beam ~1.58mA. 18 bunches with e-Gun pulse width set to 35ns


File Control Setup Trigger Measure Analyze Utilities Help
9 May 2014 10:56 AM
10.0 GSa/s 50.0 kpts
200 mV/
1.00 V/
Camshaft filling pattern
There was 0.6mA in the single bunch and
13.1mA in 1000 bunches.
Reflection signal
from single bunch
More
(1 of 2)
Delete
All
500 ns/
0.0 s
1.00 V

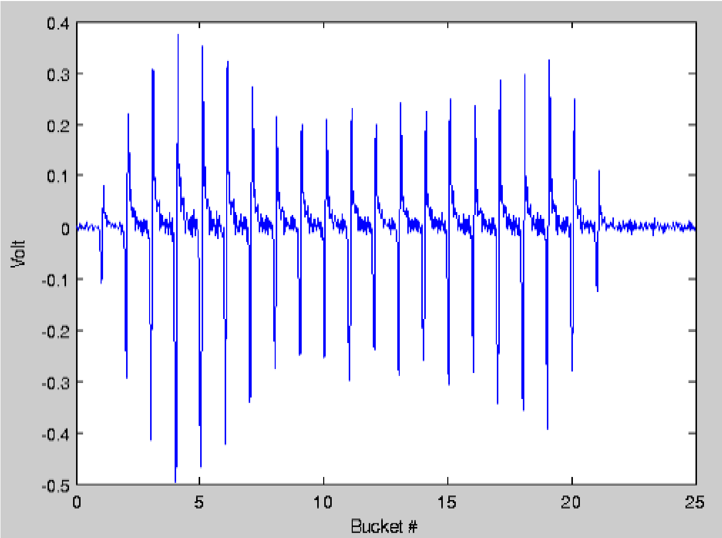

File Control Setup Trigger Measure Analyze Utilities Help
9 May 2014 12:46 PM
10.0 GSa/s 50.0 kpts
100 mV/
1.00 V/
4-bunch train, 80% fill, Itotal = 22mA
More (1 of 2)
Delete All
500 ns/
0.0 s
1.00 V

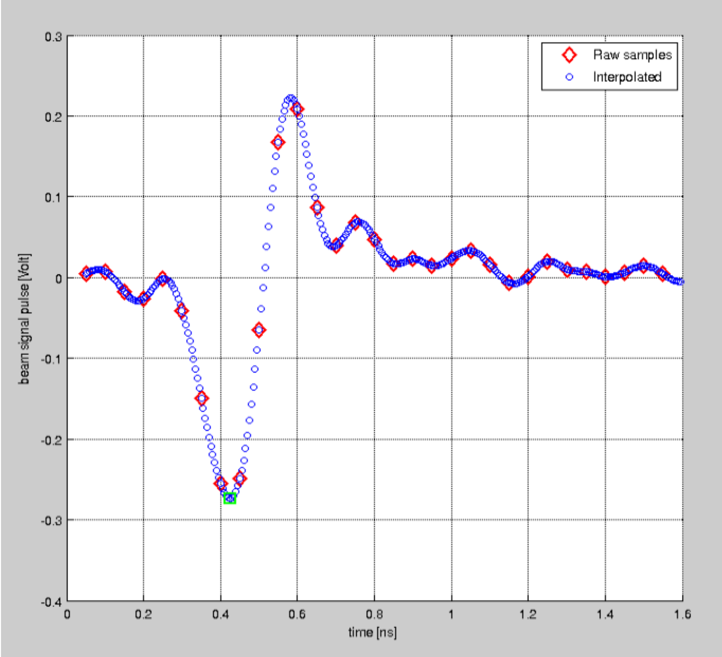


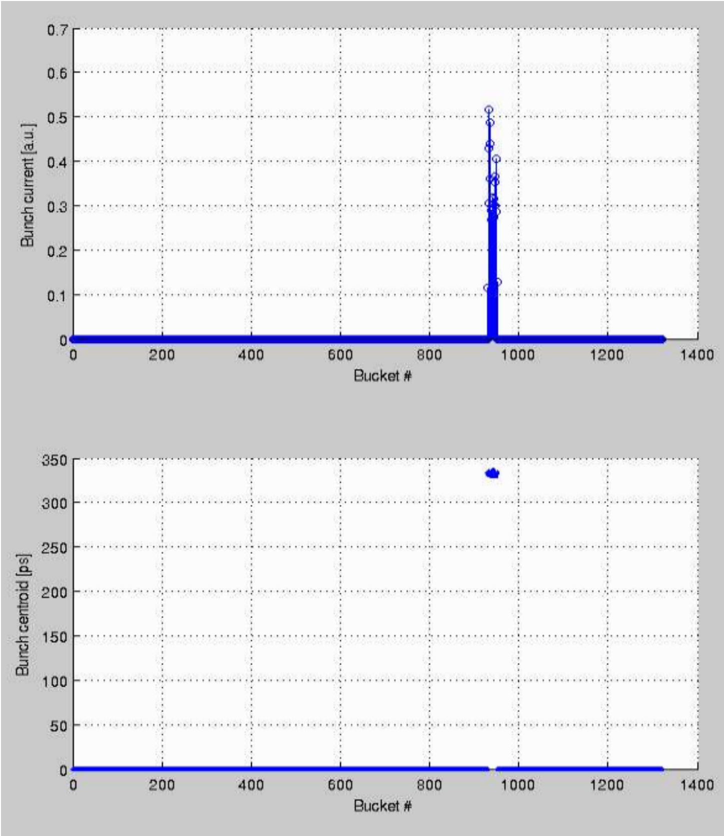
File Control Setup Trigger Measure Analyze Utilities Help
11 Jul 2014 7:06 PM
10.0 GSa/s 5.34 Mpts
1 On 200 mV/
2 On 1.00 V/
3 On
4 On
~ 47mA, one bunch train, 80% fill
More (1 of 2)
Delete All
500 ns/
920.0000 ns
540 mV

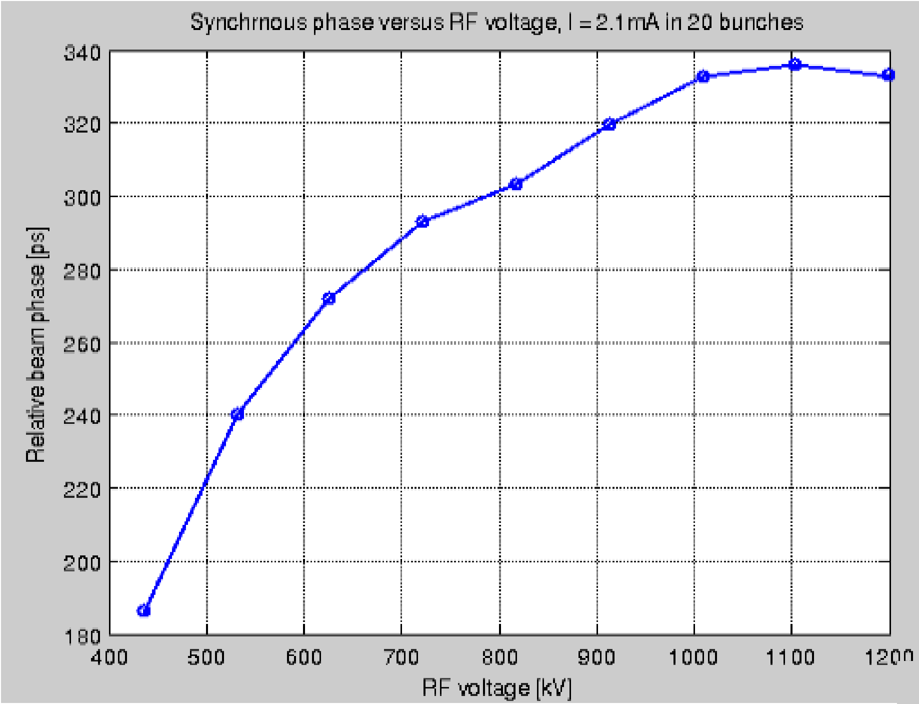
FPM to measure synchronous phase

2014-Jul-13 data, use FPM to measure synchronous phase at various Vrf, keep the current same and filling pattern. I = 2.1mA, 20-bunches in one bunch train.









$\phi_s = \phi_0 + \phi_m$

ϕ_m - measured phase

ϕ_0 - constant due to delays

ϕ_s - synchronous phase

$$eV_{rf} \sin\phi_s = U = U_{sr} + U_{pm}$$

At low current, neglect parasitic energy loss

$$eV_{rf} \sin\phi_m \cos\phi_0 + eV_{rf} \cos\phi_m \sin\phi_0 = U_{sr}$$

$$x = eV_{rf} \cos\phi_m$$

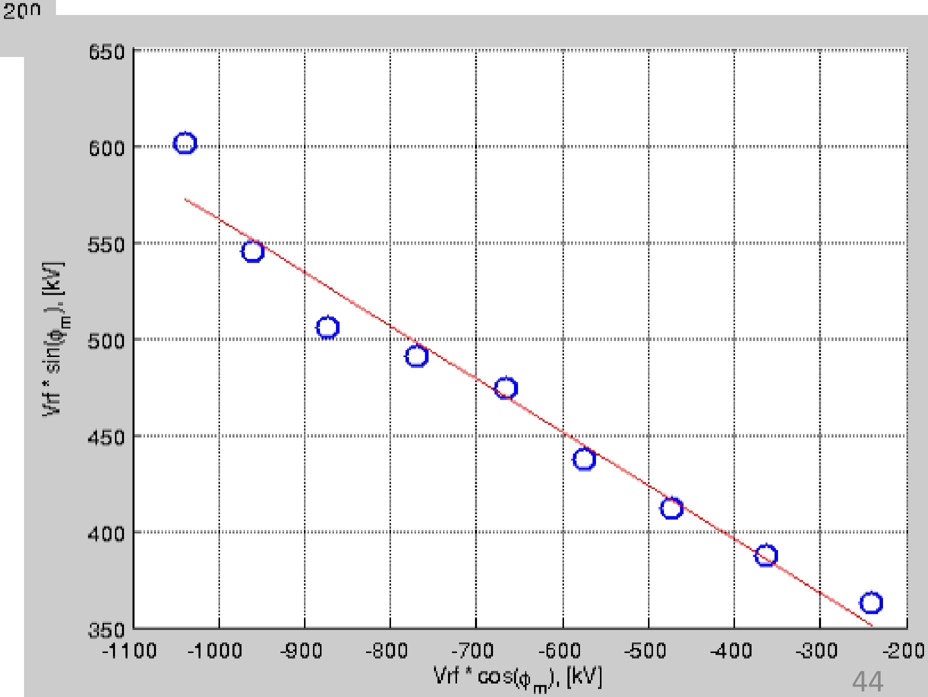
$$y = eV_{rf} \sin\phi_m$$

$$y\cos\phi_0 + x\sin\phi_0 = U_s$$

Measured energy loss per turn was 274.74 kV

287 kV from ideal lattice, w/o DW.

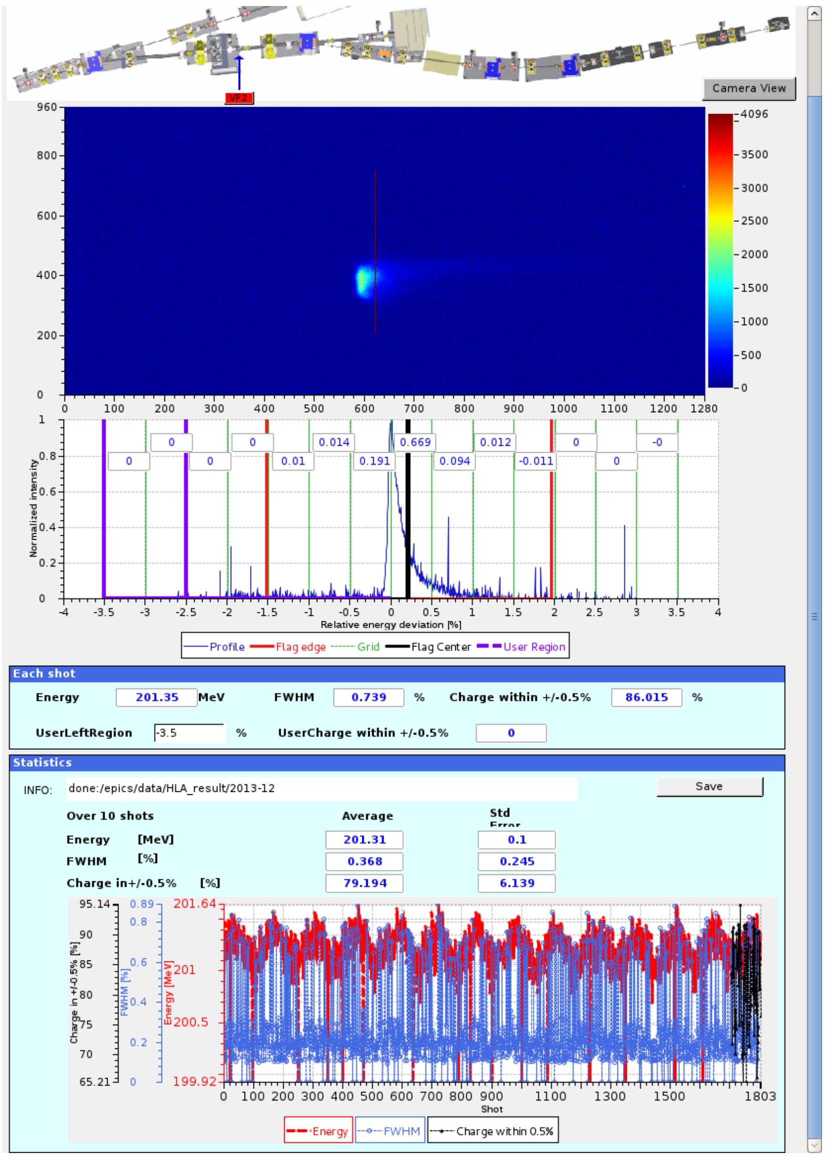
Within 5% difference



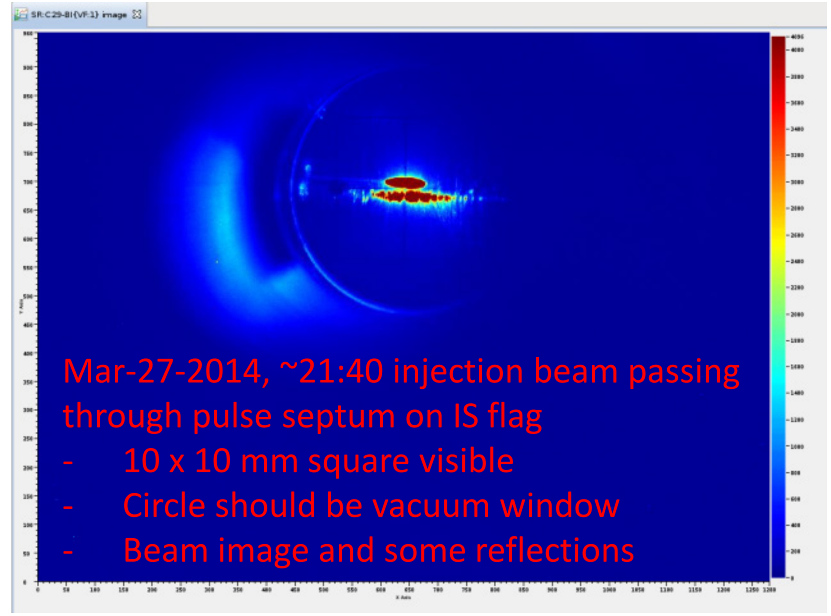
3. Profile monitors

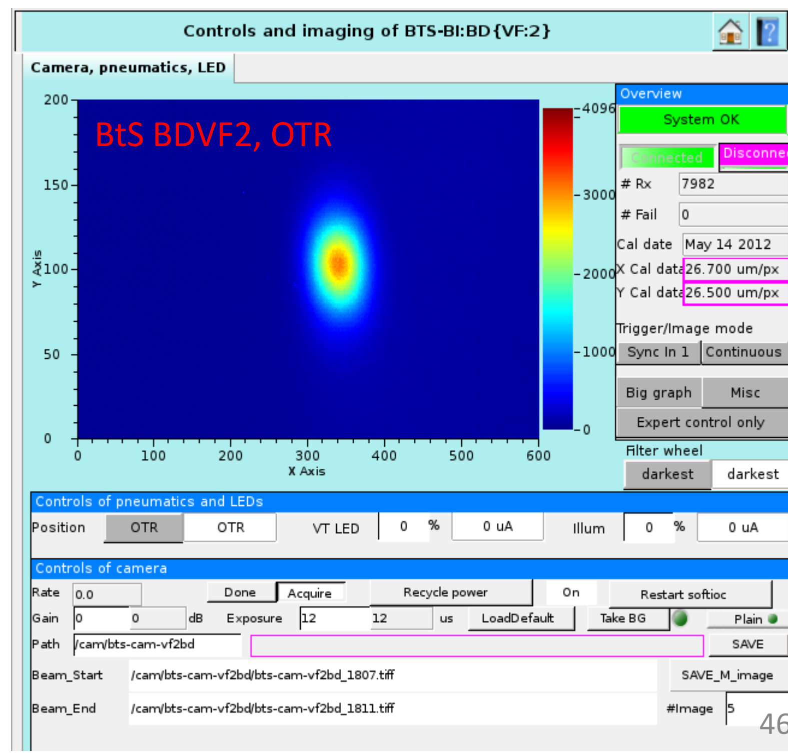
(Flags, visible SLM, x-ray diagnostics)

Profile monitor – injector flags

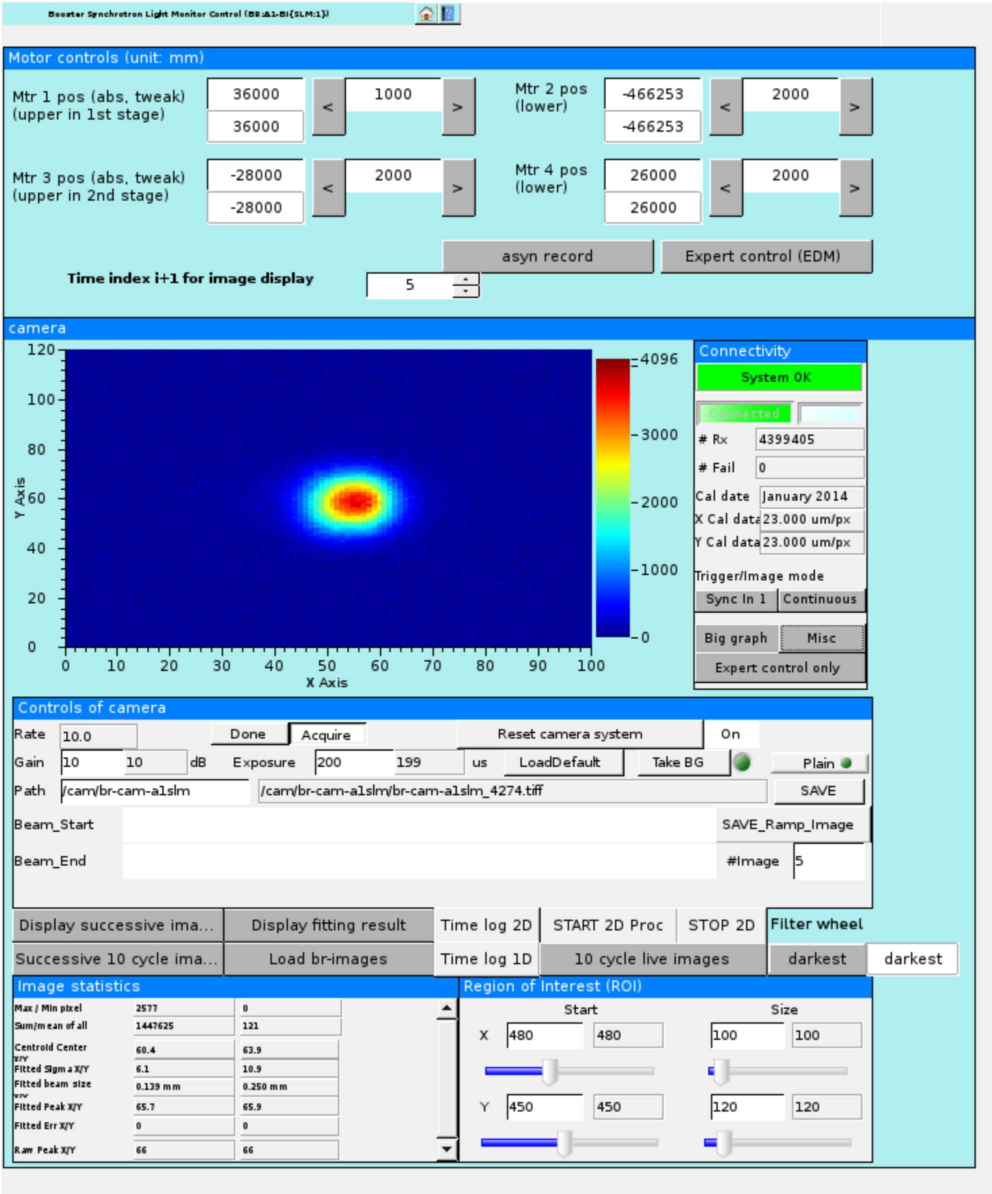


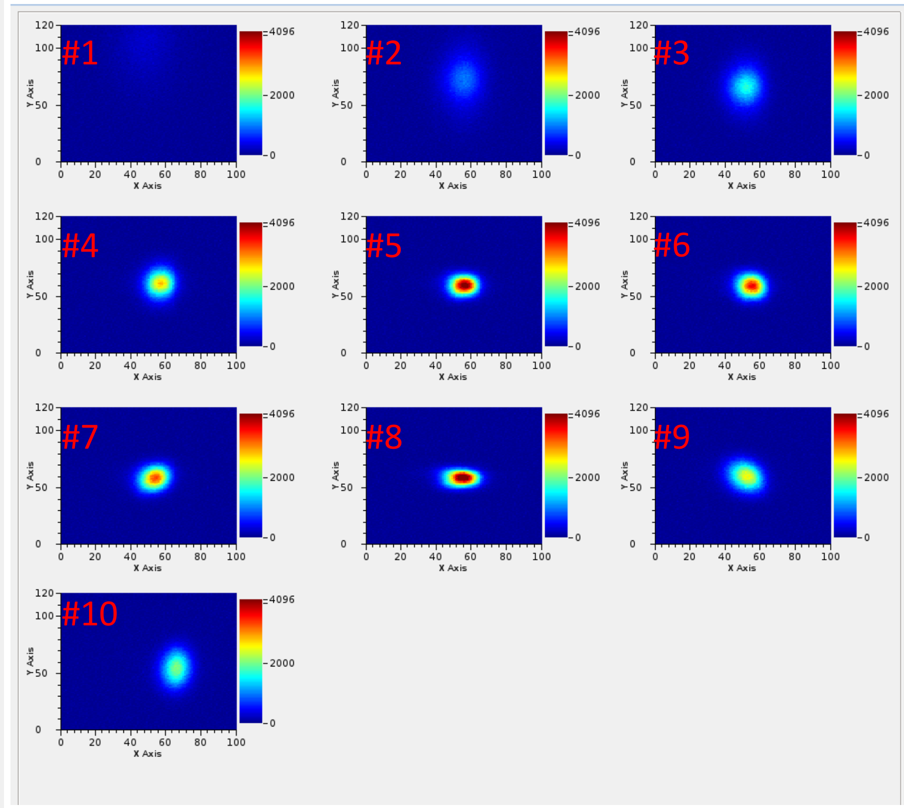
Energy jitter and energy spread measurement, using LtB VF2.





Profile monitors - Booster SLM

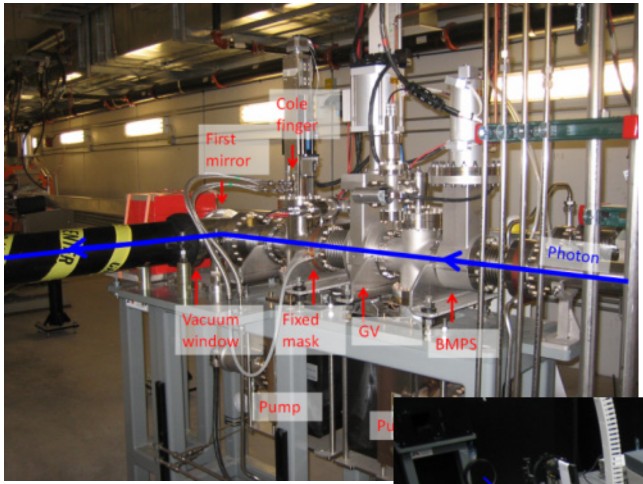


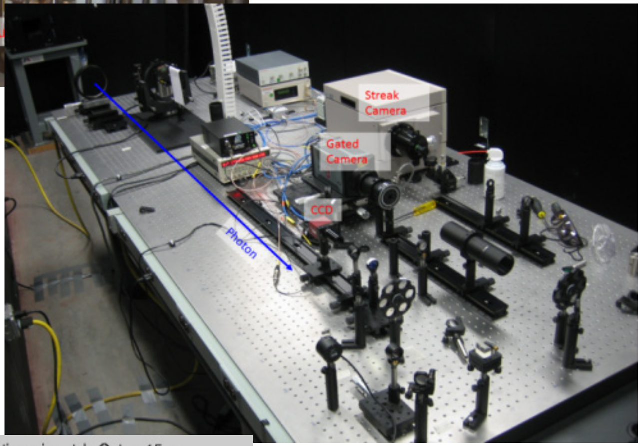


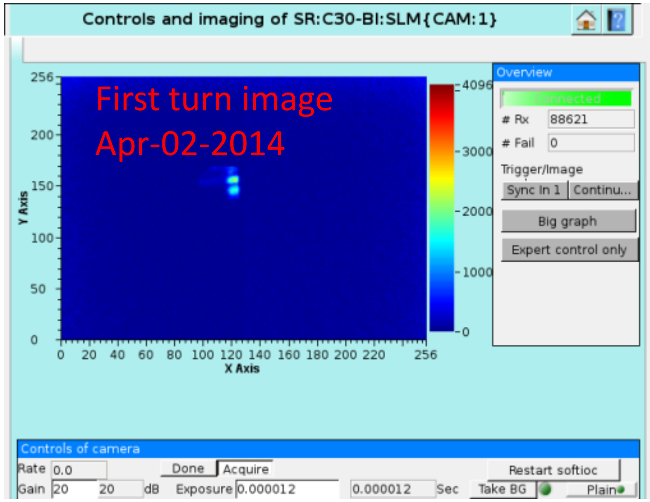
10 burst images acquired on the same booster ramp cycle, separate by 40ms

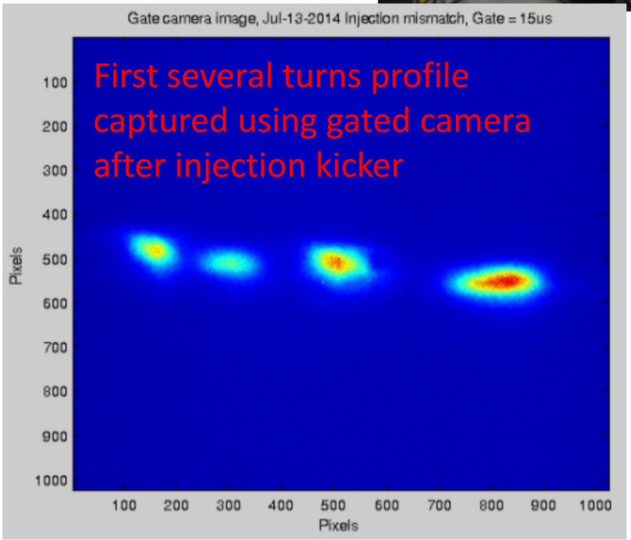
Profile monitors – Visible SLM

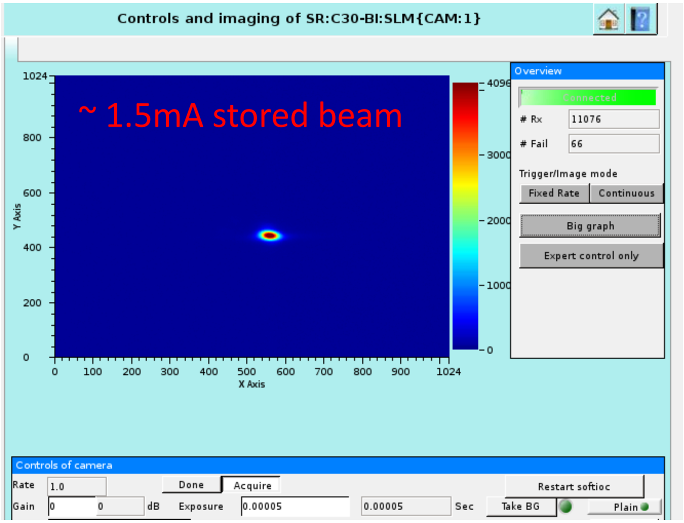
TUPF21



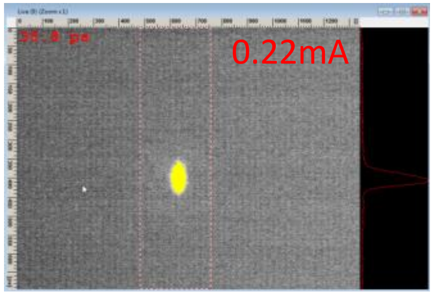


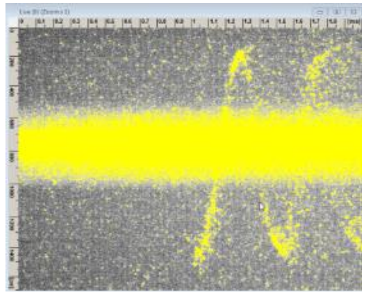


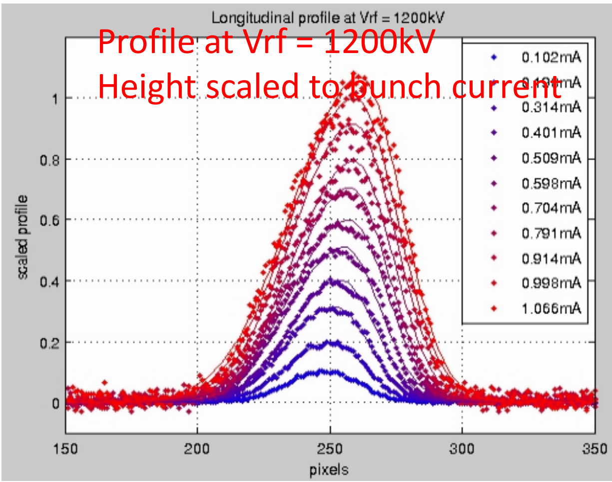


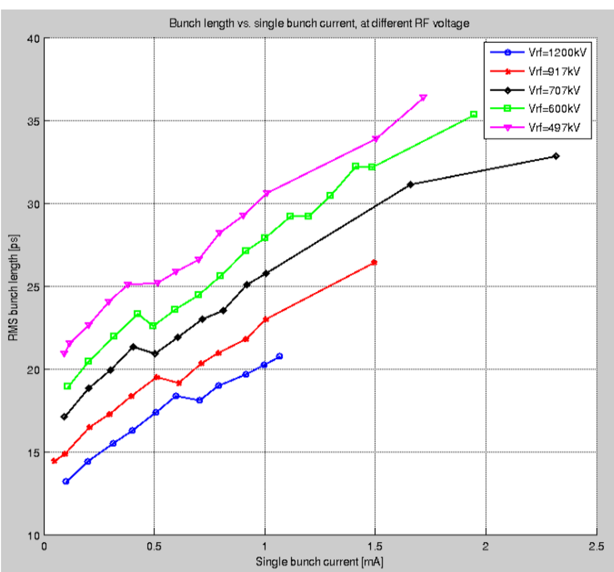


Streak camera measurements



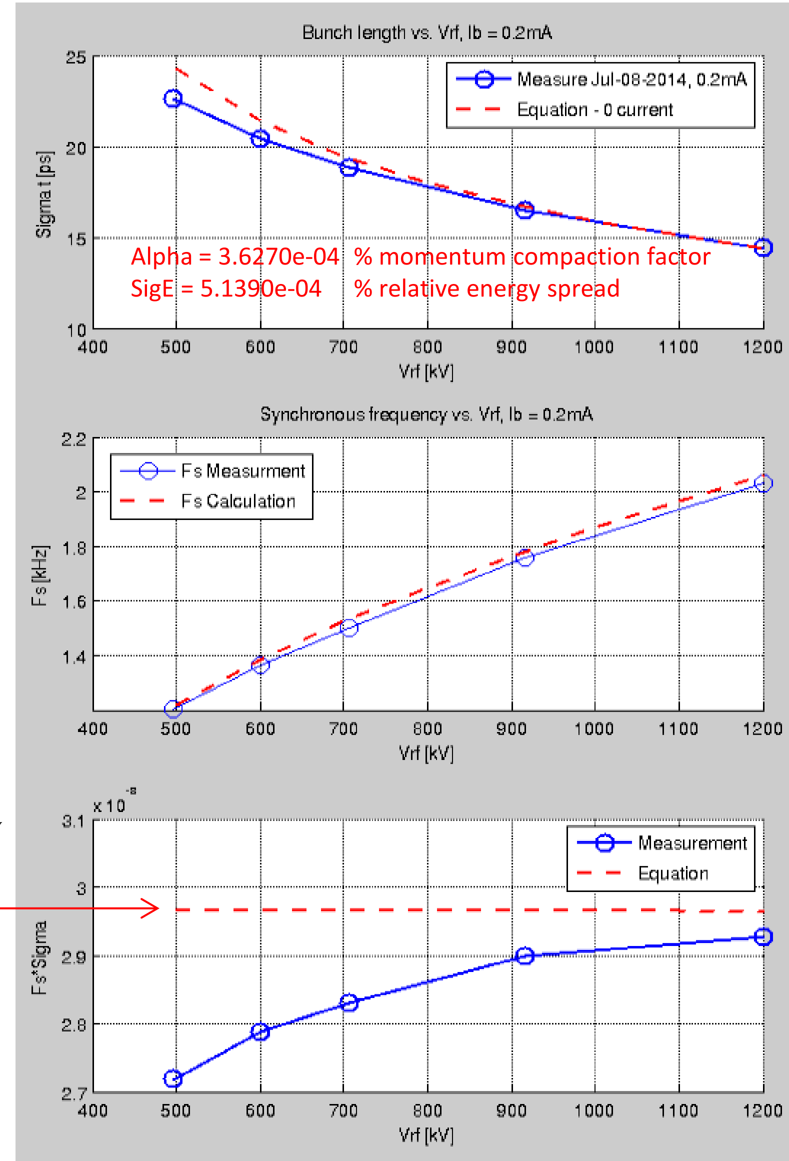






from $\sigma_t = \dfrac{\alpha}{2\pi f_s}\left(\dfrac{\sigma_E}{E}\right)$, we know

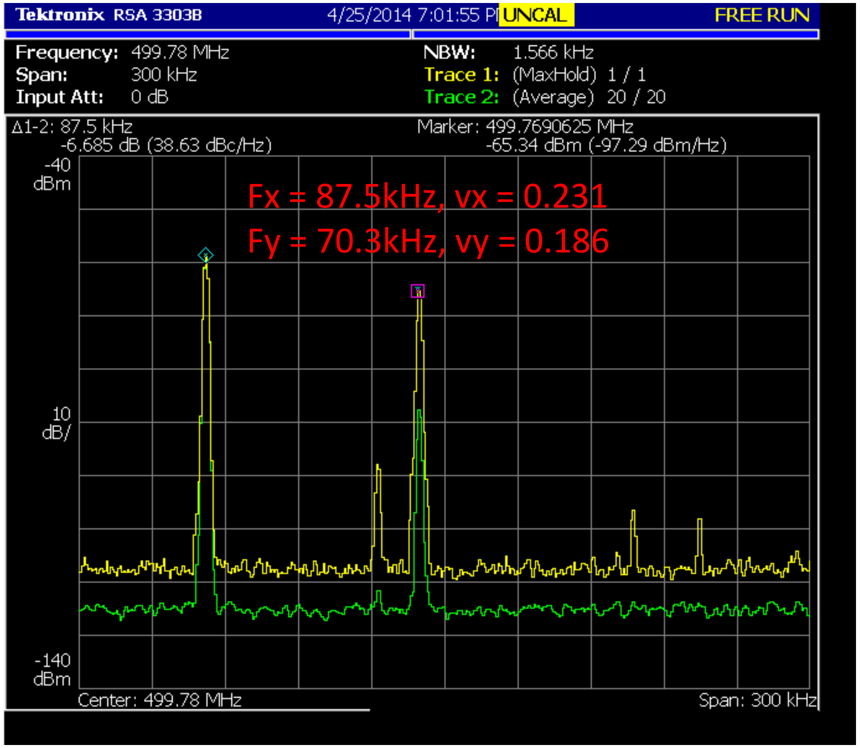
$$\sigma_t \cdot f_s = \frac{\alpha}{2\pi}\left(\frac{\sigma_E}{E}\right) = 2.97\text{e-}8$$

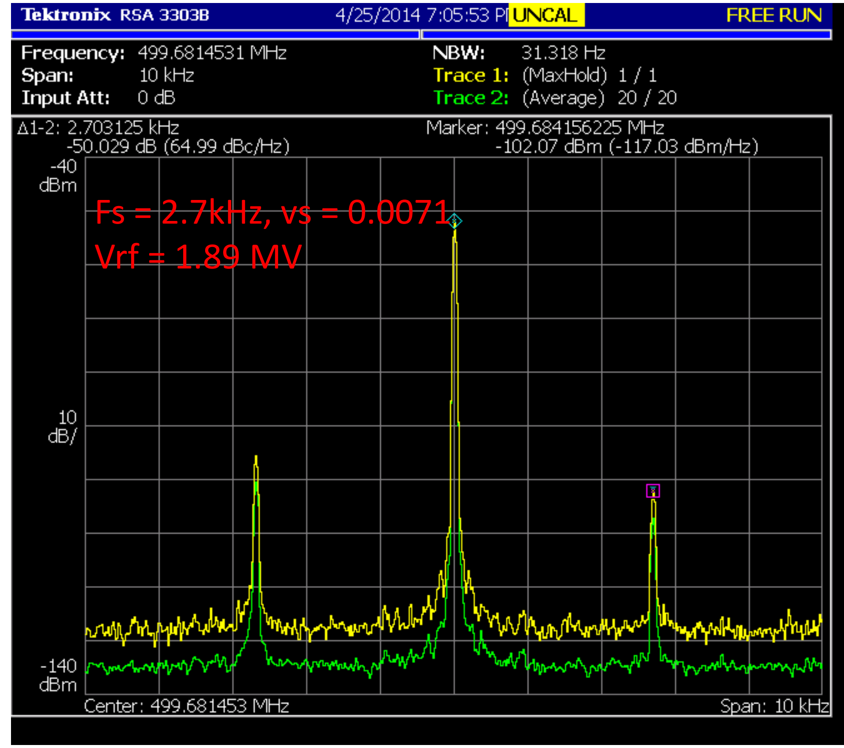


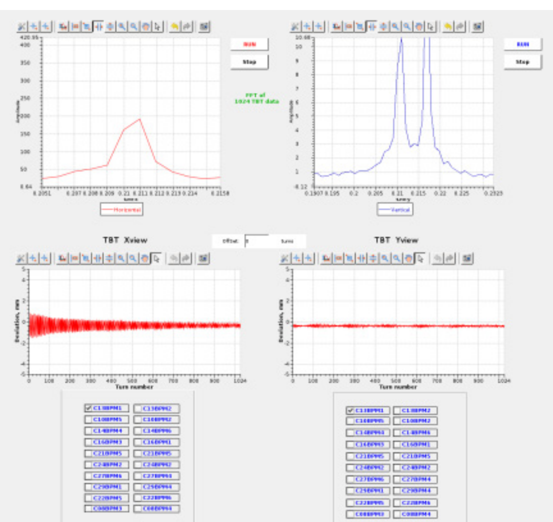
4. Other diagnostics

(TMS, BxB feedback, FFT spectrum etc.)

Beam spectrum and tune

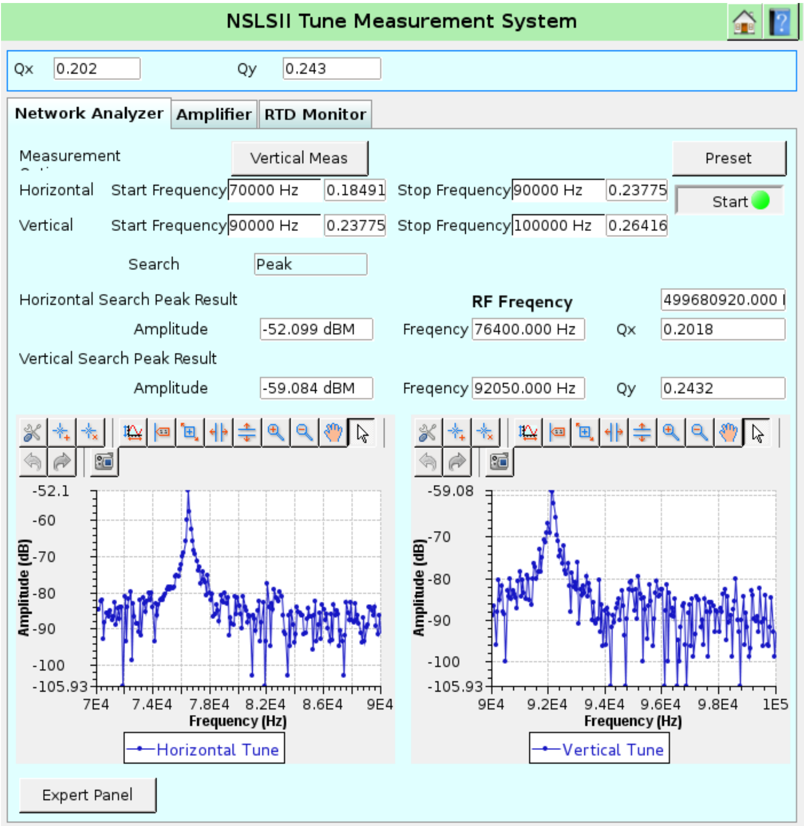






Methods to measure tunes

- FFT spectrum with pulse kicker
- BPM TbT Fourier spectrum with pulse kicker
- TMS network analyzer with sweeping excitation
- BxB feedback spectrum or transfer function
- Others (phase advance, LOCO etc)



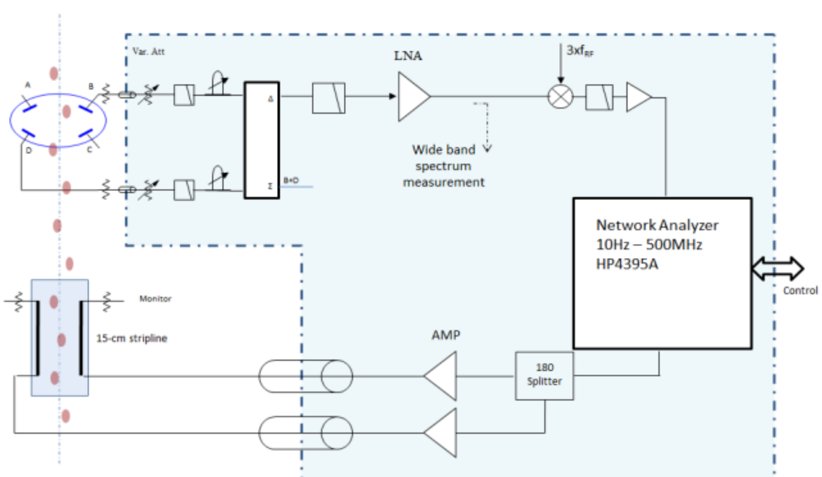
TMS – sweeping tune measurement

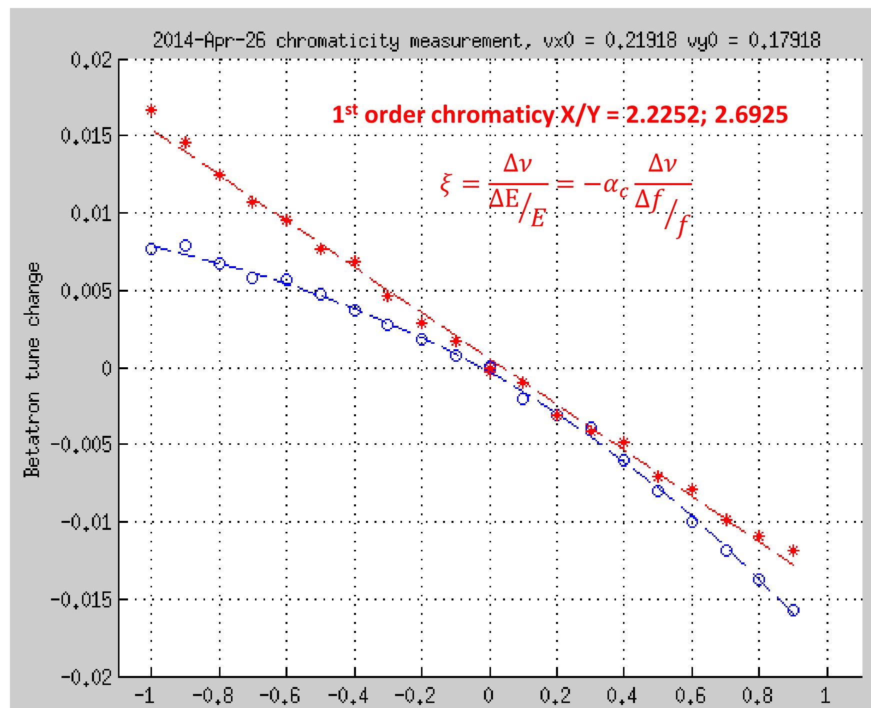
TMS measures betatron tune with 1e-4 resolution

Worked fine at very low current, 0.1mA in multi-bunches

NA sweep time 1-2 seconds

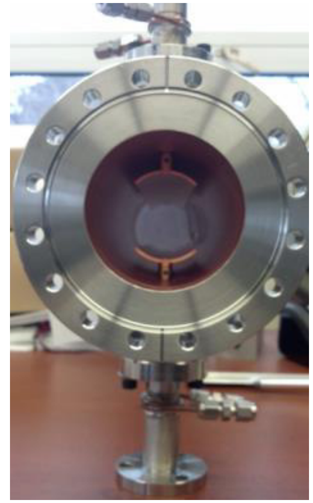
15cm stripline kicker, 75W broadband amplifiers

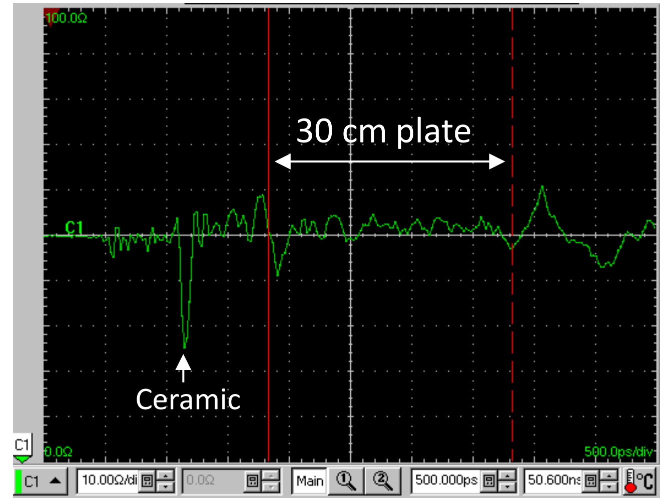




BxB feedback commissioning

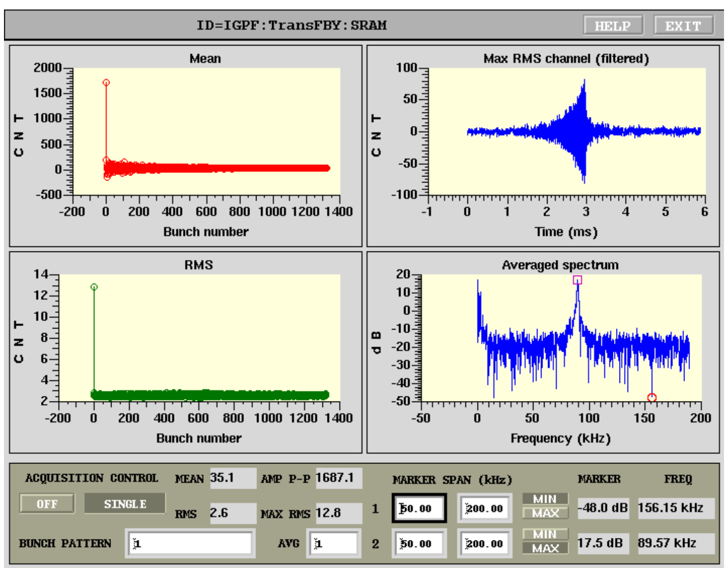
WEPD27



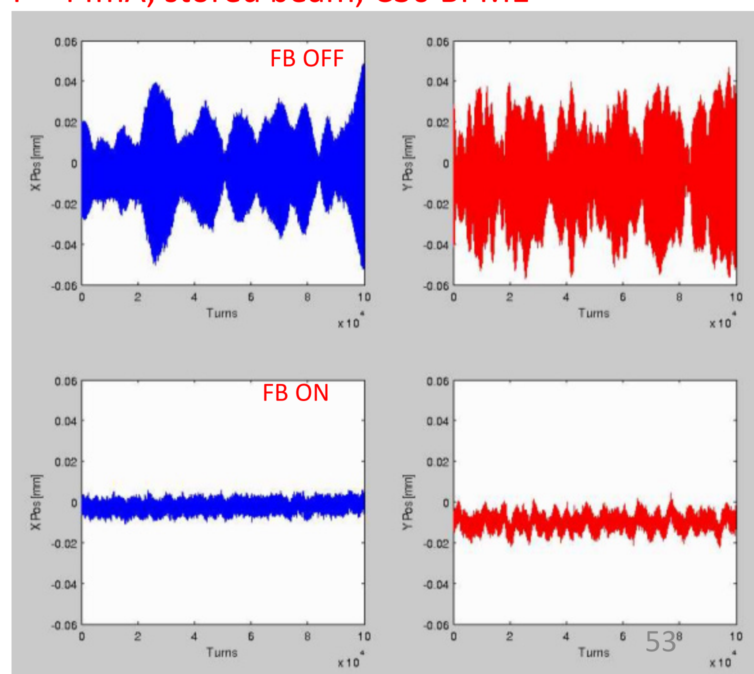


Single bunch, I_b = 4.5mA

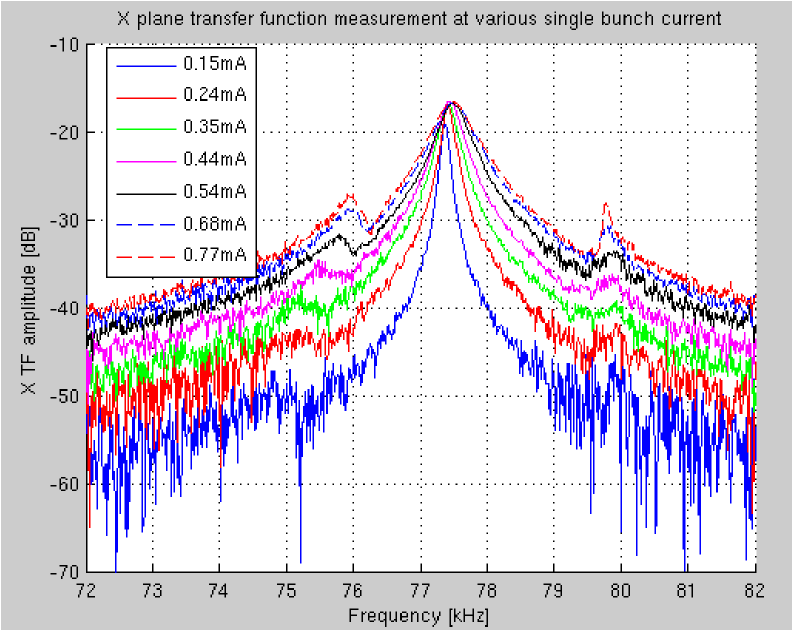
Y plane growth-damp measurement, feedback OFF for 3ms and recaptures

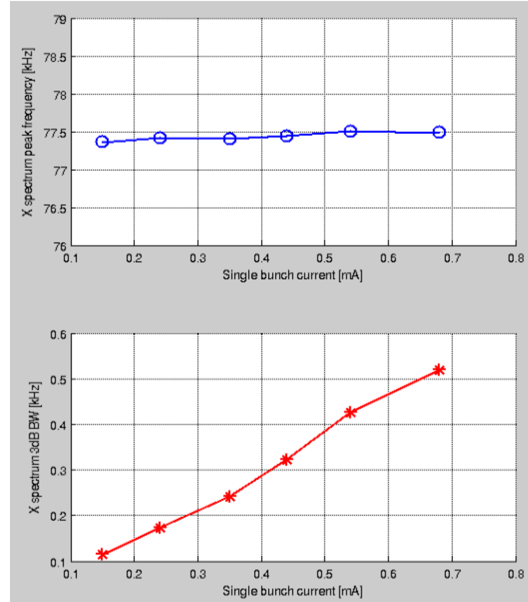


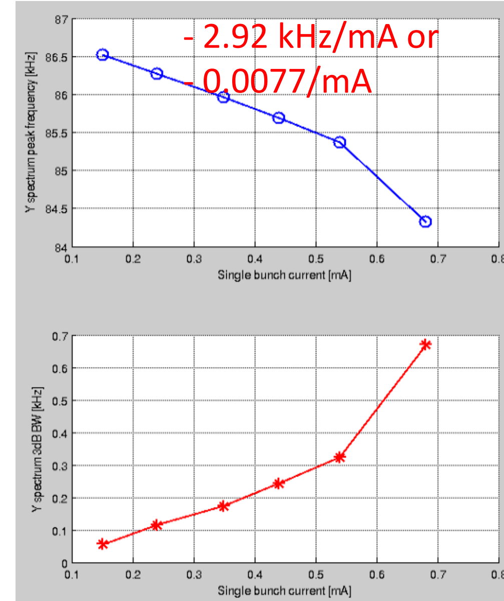
I = 44mA, stored beam, C30 BPM1

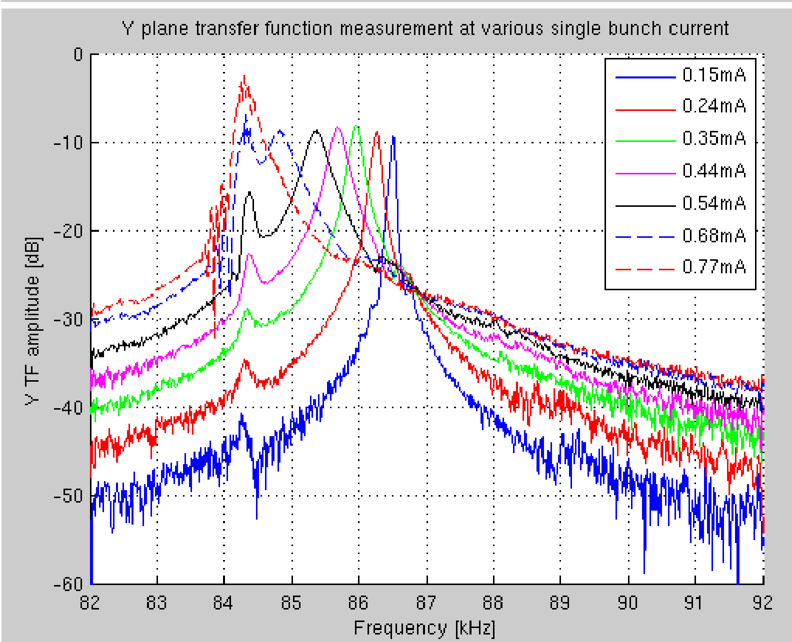


Single bunch transfer function measurement









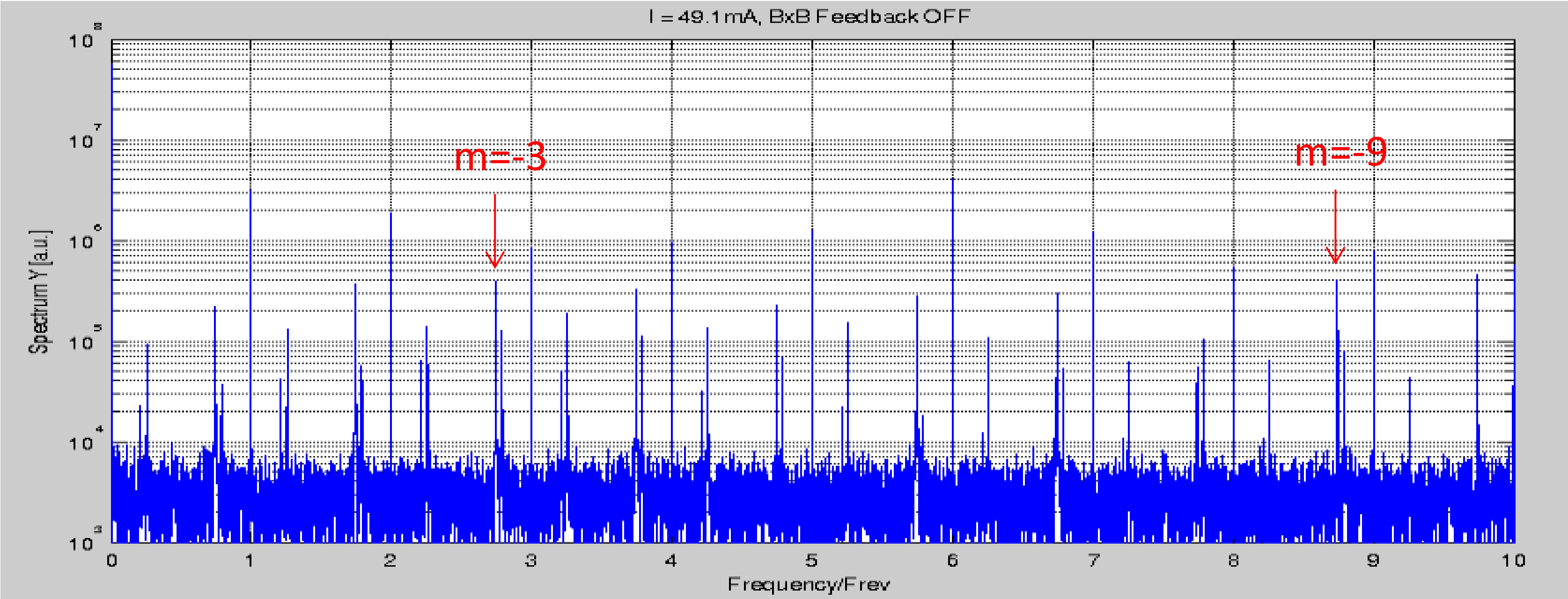
Vertical plane tune spectrum at different single bunch current looks like TMCI

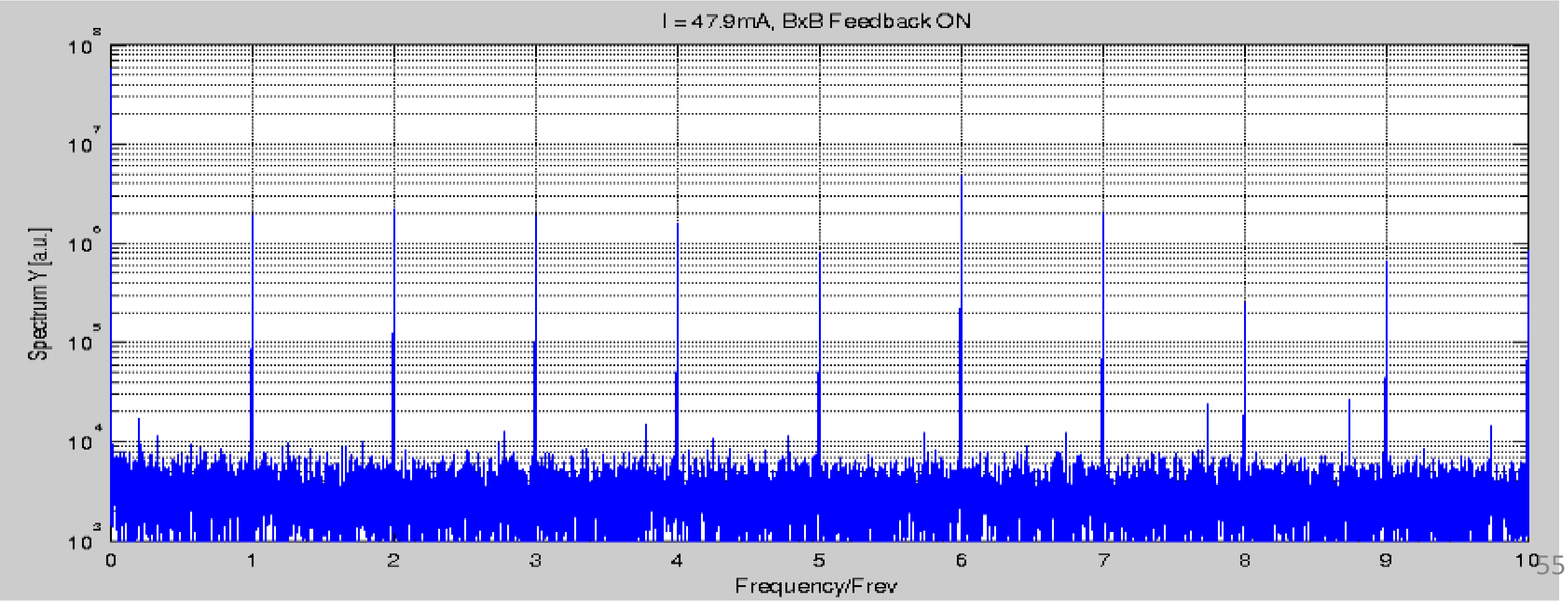
Horizontal plane peak position doesn’t move much.

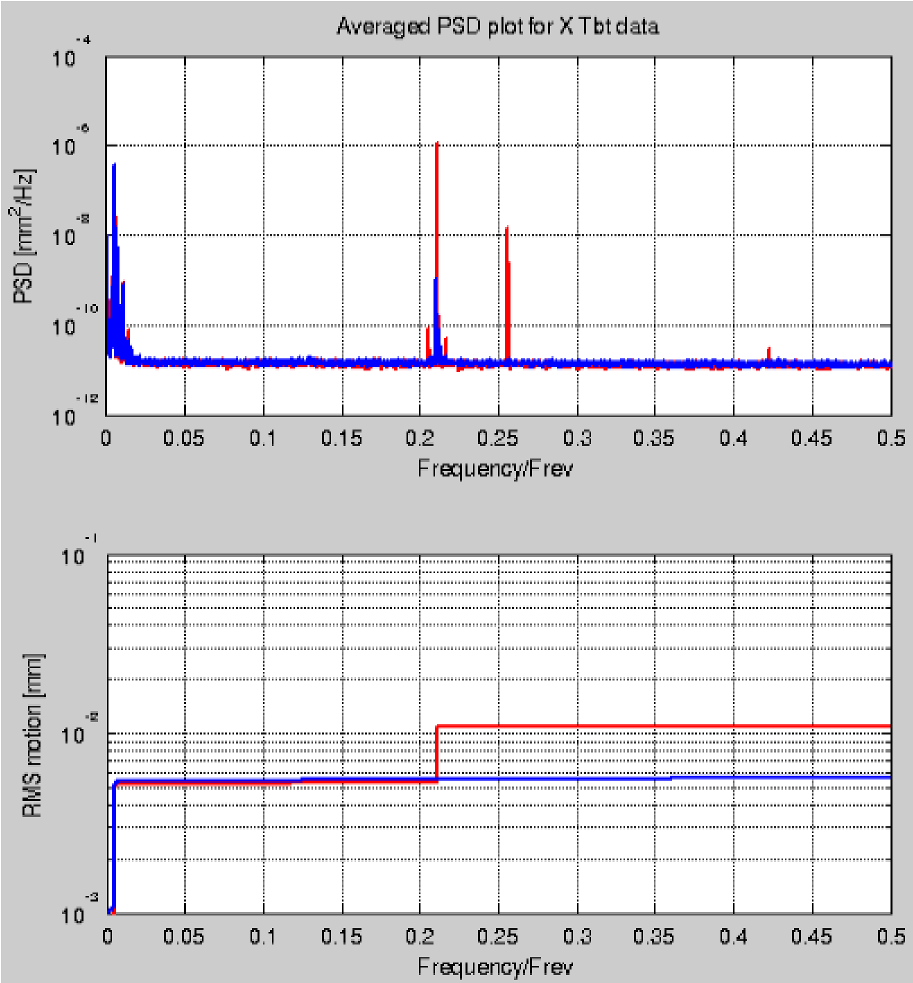
- 2.92kHz/mA (0.0077/mA) slope, agrees with other method results.

3dB bandwidth increasing as the single bunch current increased.

Unstable modes analysis, 1024 turns data of 1320 buckets





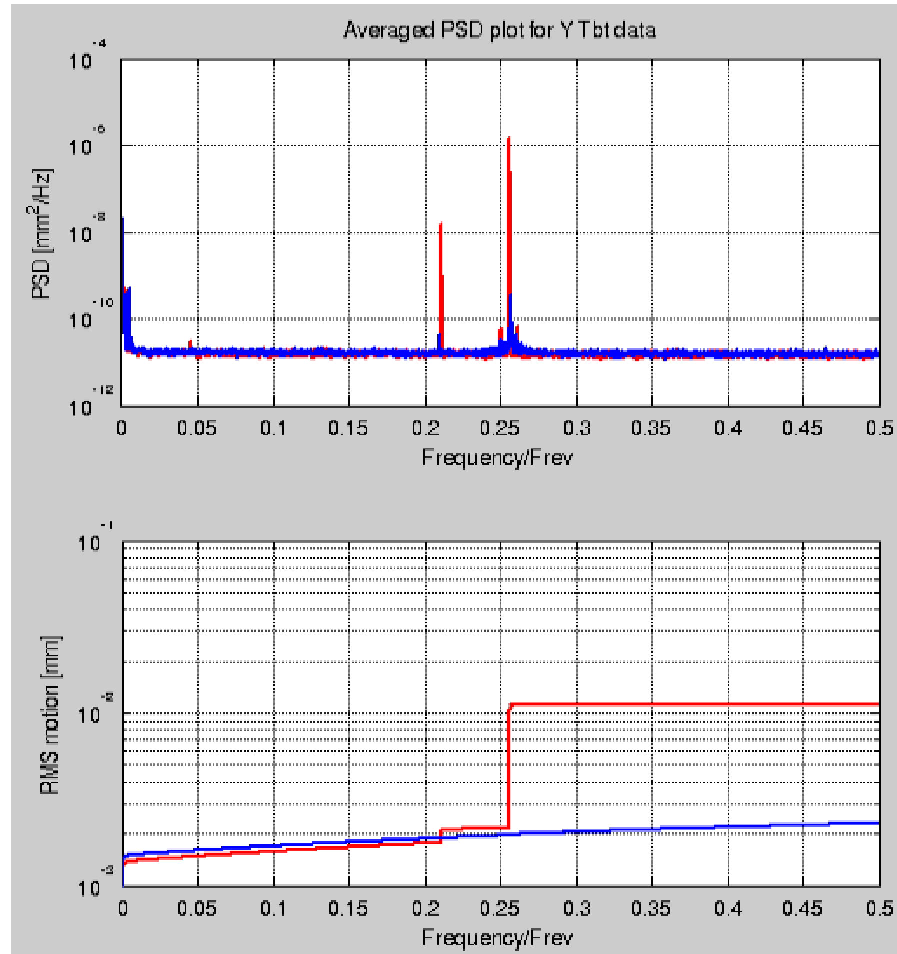


Compare BPM TbT spectrum with BxB ON/OFF

Data at around 2014Jul11_2040, I ~44mA

Red – Feedback OFF
Blue – Feedback ON

> 30 dB suppression of betatron motions sideband



Summary

- 50mA stored beam achieved in NSLS2 storage ring, with SC RF cavity
- ID commissioning, higher current high stability beam will continue in coming months
- Most of NSLS2 diagnostics have been commissioned with beam. Machine characterized and optimized using these powerful tools. These diagnostics will play important roles for further understanding and development of the machine. Some highlights include:
  - Beam motion measured to be ~ 2um RMS (< kHz)
  - Reliable current and lifetime measurement
  - First synchrotron light on the NSLS2 experiment floor (visible light)
  - Single bunch and coupled bunch instabilities suppression
- NSLS2 contributions at the conference:
  - **MOPF03** NSLSII Photon Beam Position Monitor Testing
  - **MOPF07** Construction and Operational Performance of a Horizontally Adjustable Beam Profile Monitor at NSLS-II
  - **MOPF20** Diagnosing NSLS-II -- the World's Most Advanced Synchrotron Light Source
  - **TUPF01** NSLS-II RF Beam Position Monitor- System Test and Integration
  - **TUPF21** NSLS2 Visible Synchrotron Light Monitor Diagnostic Beamline Commissioning
  - **WECYB2** NSLS-II RF Beam Position Monitor Commissioning Update
  - **WEPD27** Commissioning of Bunch-by-Bunch Feedback System for NSLS2 Storage Ring
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