First Collective Effects Measurements in NSLS-II with Insertion Devices

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BNL/NSLS-II
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6th International Particle Accelerator Conference

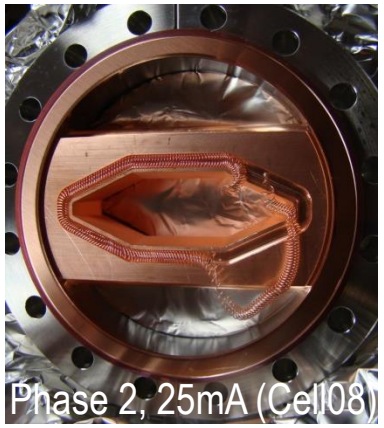
Outlook

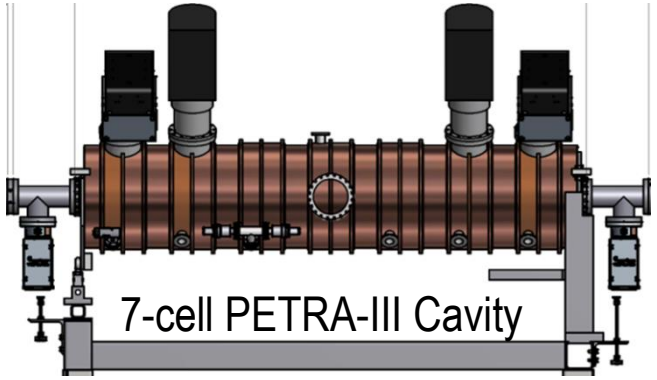
- Average Current of 200mA Achieved (500mA goal)
- Single-Bunch Transverse Instability Threshold
- Effects of 4IVUs on the Transverse Instability Threshold
- Multi-Bunch Instability Thresholds
- Summary

NSLS-II Commissioning

30 Mar. 2014	1st turn around SR is complete
31 Mar. 2014	3 turns complete
3 Apr. 2014	Wrong kicker polarity found and fixed. Circulating beam about 14 turns
4 Apr. 2014	Circulating beam ~50 turns
5 Apr. 2014	Beam up to 200 turns. Turned on the sextupoles, retuned the BTS/orbit, almost 300 turns. RF is ON.
8 Apr. 2014	Storing up to about 0.25mA (70% inj. effic.)
16 Apr. 2014	0.5mA one-shot injection with on-axis Inject. Accumulated >2.6mA in multi-bunch
23 Apr. 2014	Local vertical bump in BPMs 62/63 shown an obstacle in vacuum chamber
25 Apr. 2014	After opening up the 3rd bellows, an RF contact spring was found in cell10
29 Apr. 2014	First time at 25mA within ~1000 bunches with PETRA-III 7-Cell NC RF Cavity!
11 May 2014	Shutdown for ID installation

- Difficulties in orbit correction. RF Spring in Cell10
- The fan burned through the spring in Cell 08
- The assembly method needs to revised



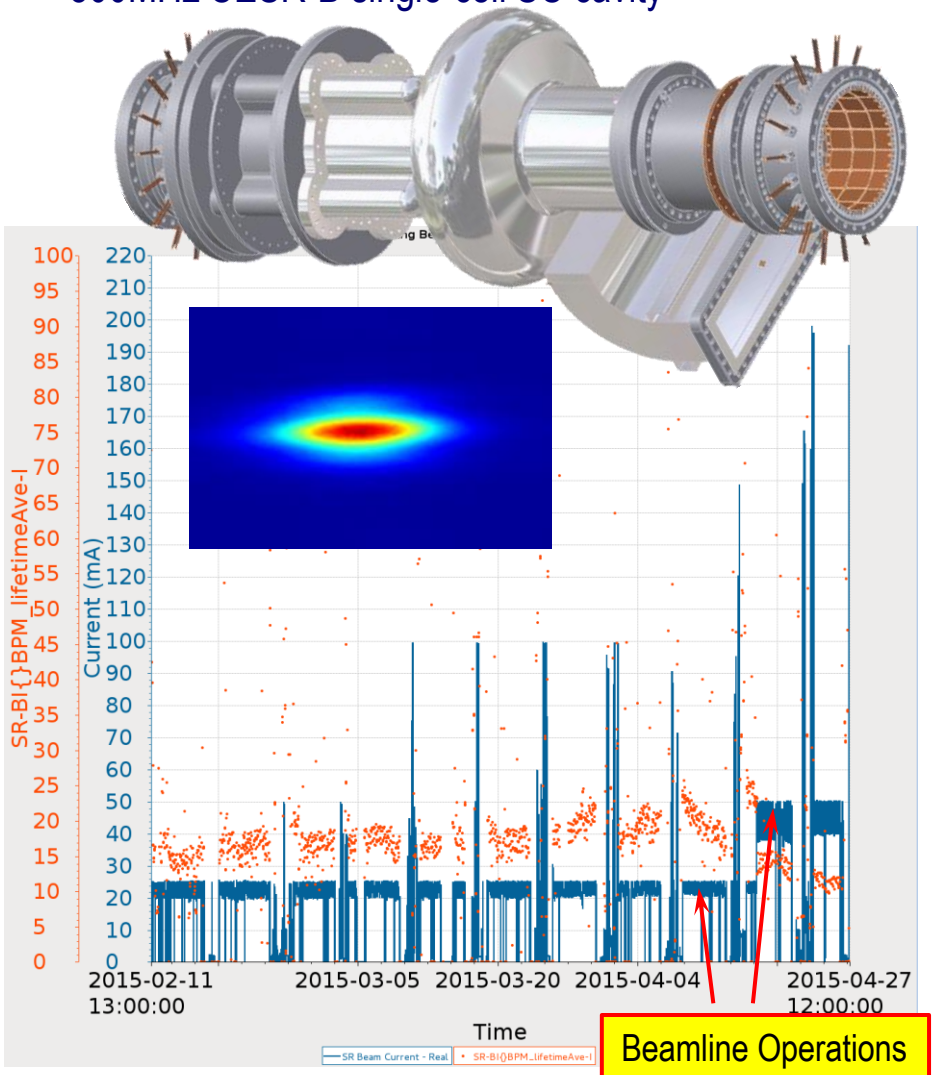


- PETRA-III 7-Cell spare cavity for the NSLS-II Booster used to achieve 25 mA in the Storage Ring
- Longitudinal Coupled-Bunch Instabilities due to HOM

NSLS-II Beam Intensity Increasing

02 Jul. 2014	25 mA with CESR-B SC RF cavity
11 Jul. 2014	First time at 50mA
14 Jul. 2014	Shutdown for ID and FE installation
03 Oct. 2104	Start of ID commissioning
23 Oct. 2014	First light on beamline flag!
11 Feb. 2015	**Beamline operations begins at 25 mA**
25 Feb. 2015	50 mA with IVU's magnet gap closed
11 Mar. 2015	First time at 100 mA
15 Apr. 2015	First time at 150 mA
17 Apr. 2015	**Beamline operations begins at 50 mA**
23 Apr. 2015	First time at 200 mA

- 500MHz CESR-B single-cell SC cavity

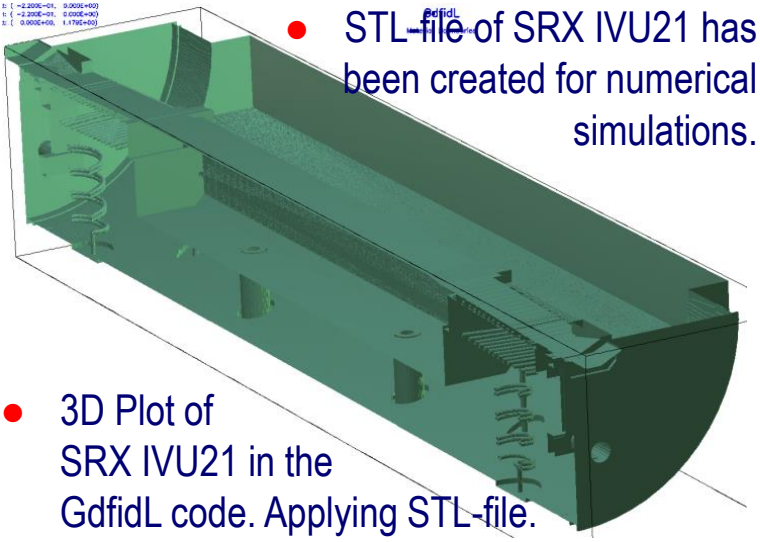


- Two days for beam studies each week after beamline operation begins
- TFB system or positive chromaticity effect keep beam motion stable with 3DW's, 1EPU and 4IVU's installed only.
- More ID's installation underway

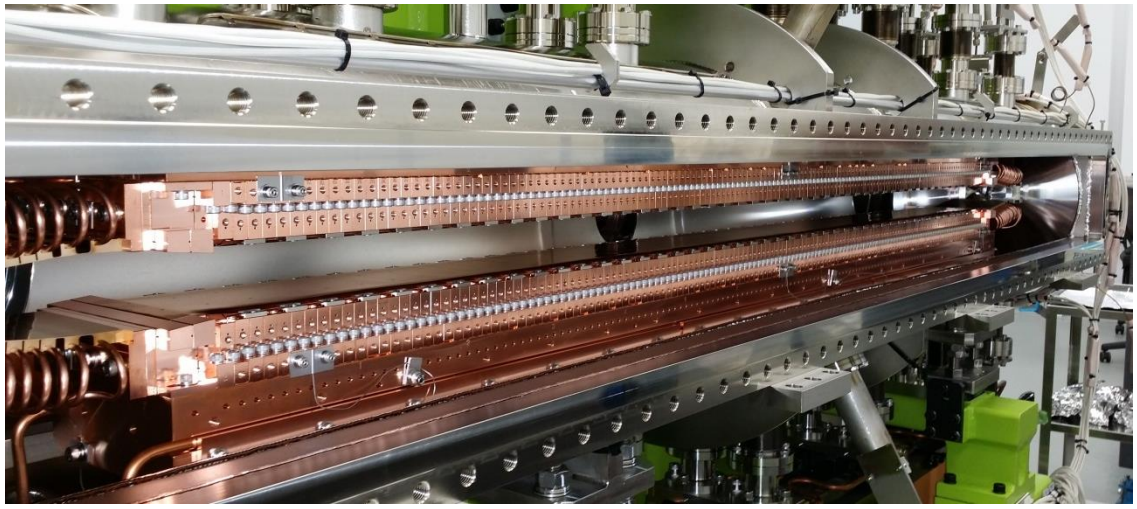
NSLS-II Parameters for the Collective Effects Characterization

Energy,	$E_0(GeV)$	3
Revolution period,	$T_0(\mu s)$	2.6
Momentum compaction,	α	3.7×10^{-4}
Energy loss,	$U(keV)$	287 (BM) 674 (BM + 3DW's)
RF voltage,	$V(MV)$	1.78
Synchrotron tune,	ν_s	6.8×10^{-3}
Damping time,	$\tau_x, \tau_s(ms)$	54, 27 (w/o DWs) 23, 11.5 (with 3DWs)
Energy spread,	$\sigma_{\varepsilon 0}$	5×10^{-4} (BM) 8.8×10^{-4} (BM + 3DW's)
Bunch duration,	$\sigma_s(mm)$	3.4 (w/o DWs) 6 (with 3DWs) Ignoring bunch lengthening

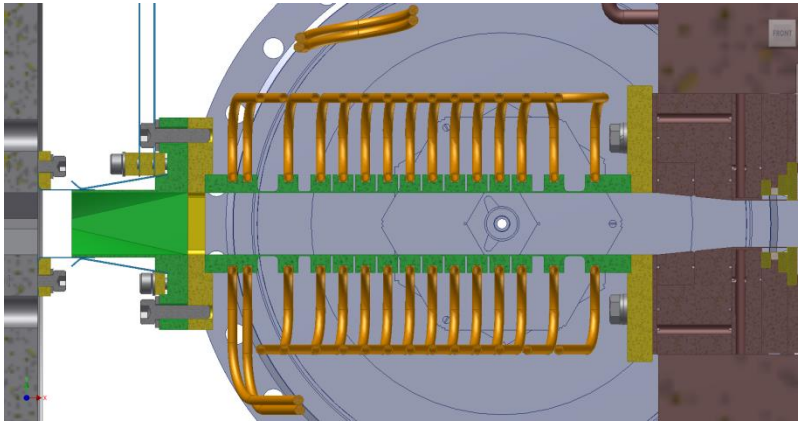
NSLS-II In-Vacuum Undulator (SRX, IVU21)



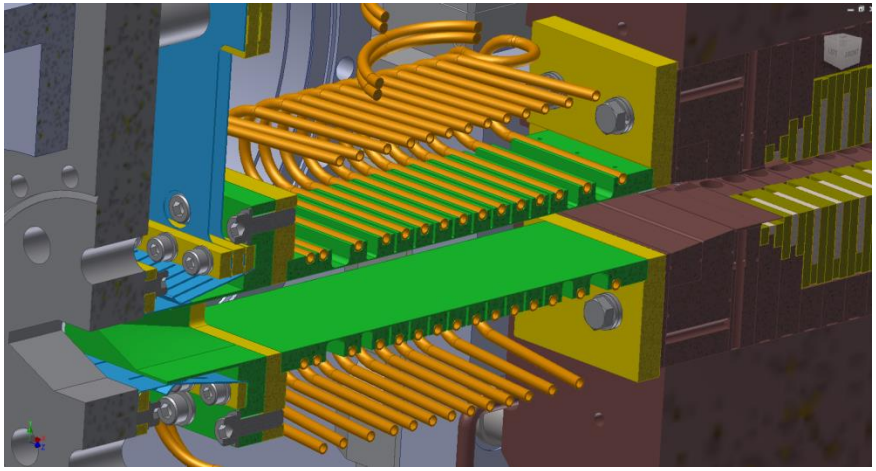
- STL-file of SRX IVU21 has been created for numerical simulations.
- 3D Plot of SRX IVU21 in the GdfidL code. Applying STL-file.



In-Vacuum Undulator (Gap Open)



Tapered Transition Side View. 3D Rendered Picture with open gap

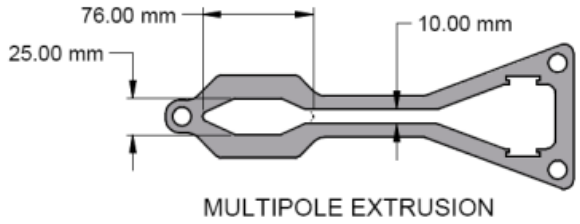


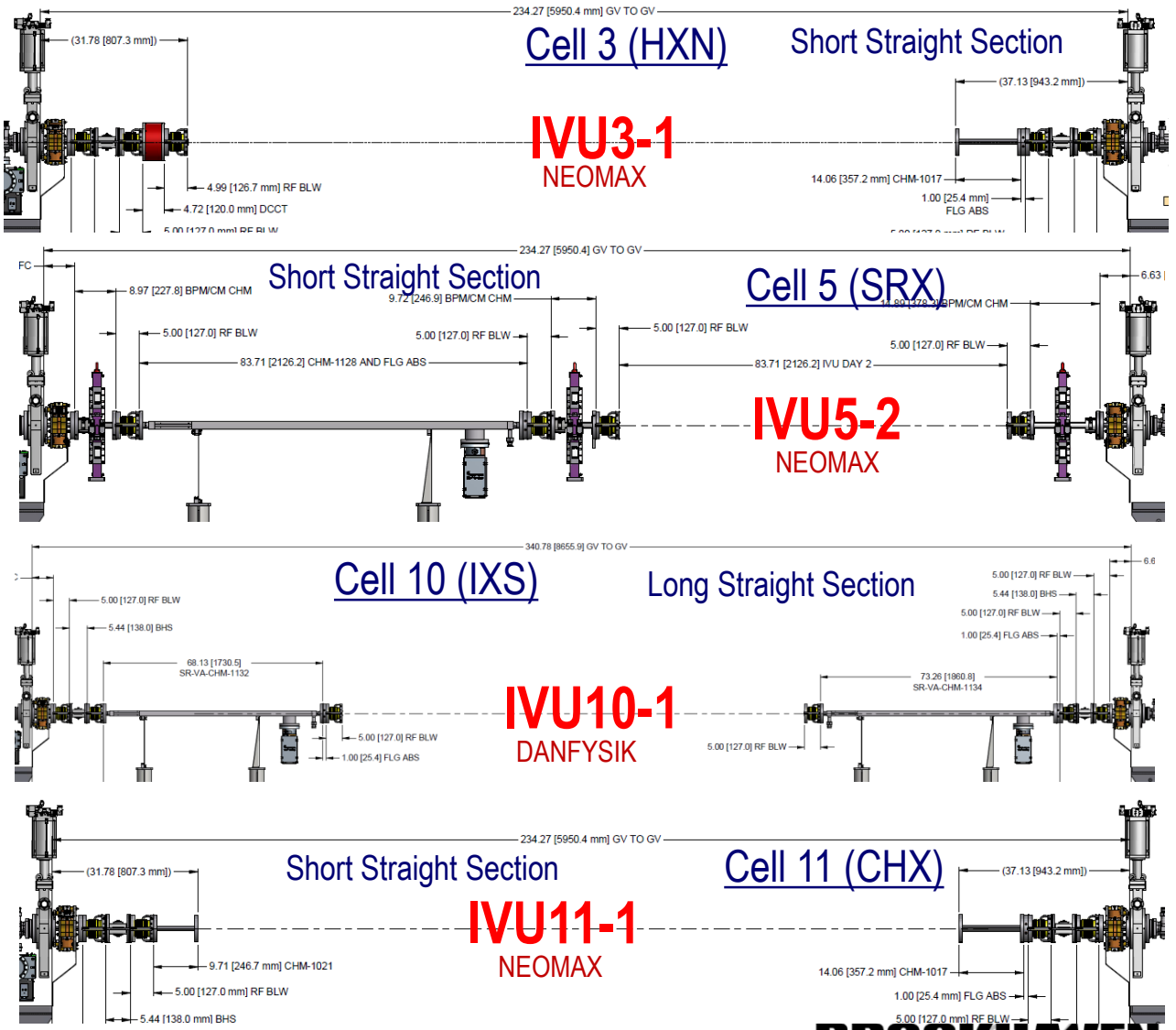
Another View of Tapered Transition

Present IVU's Location

Gaps configuration from beam point of view

ID's	Gaps Configuration	
	All Gaps Closed	All Gaps Open
IVU3-1	5mm	40mm
IVU5-2	6.5mm	40mm
DW8-1	11.5mm	11.5mm
DW8-2	11.5mm	11.5mm
DW18-1	11.5mm	11.5mm
DW18-2	11.5mm	11.5mm
DW28-1	11.5mm	11.5mm
DW28-2	11.5mm	11.5mm
IVU10-1	6mm	40mm
IVU11-1	5.5mm	40mm
EPU23-1	8mm	8mm
EPU23-2	8mm	8mm

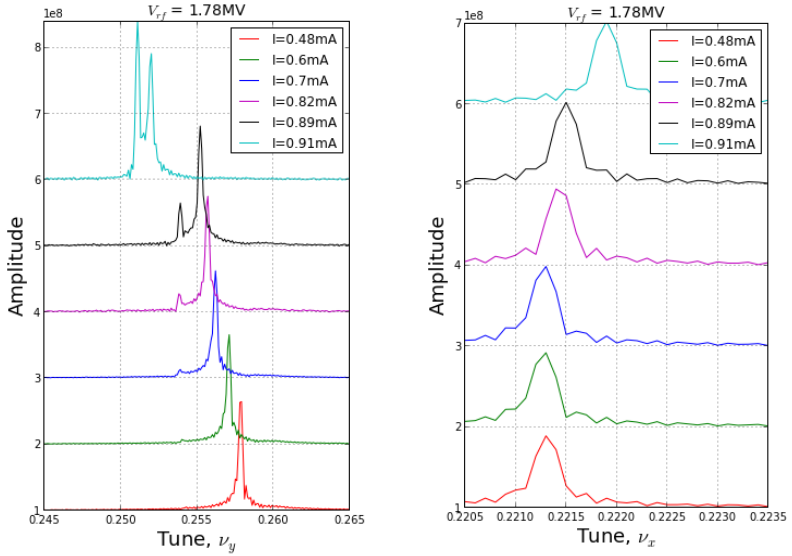




Single-Bunch Instability Threshold

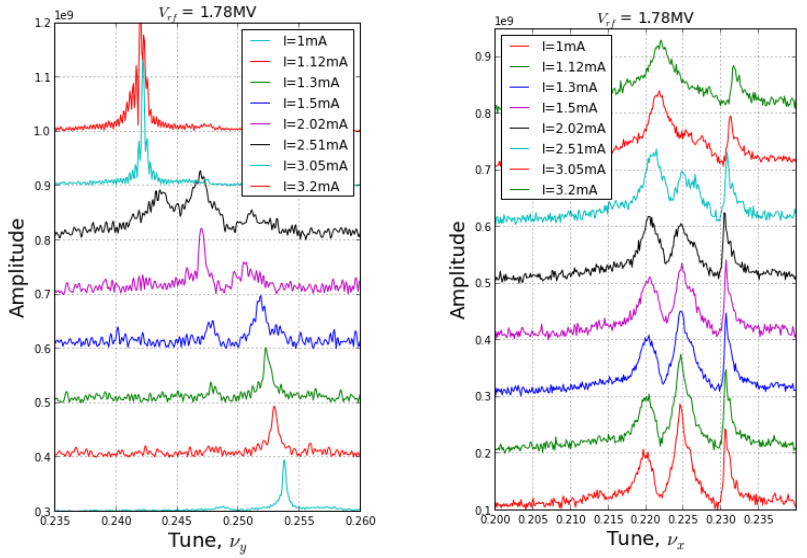
3 DW's and 4 IVUs Magnet Gap Closed ($\sigma_s = 6mm$)

Vanishing Chromaticity, I_{th}= 0.95mA



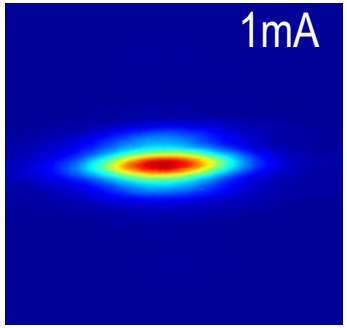
Spectra of BPM 41 vertical and horizontal TbT

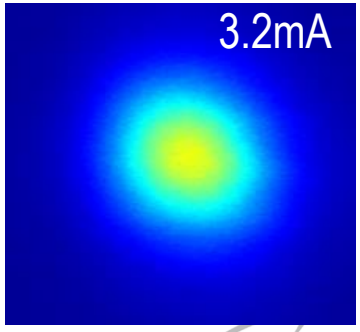
Chromaticity +5/+5, I_{th}= 3.2mA



Spectra of BPM 41 vertical and horizontal TbT

- Single Bunch Intensity Limit due to Transverse Mode Coupling Instability (TMCI)
- Positive Horizontal Tune Shifts Indicates the Dominance of the Quadrupole Impedance
- Stabilizing Effect of Positive Chromaticity, I_{th}=6mA at $\xi_{x/y}$=+7/+7 and I_{th}=3.2 at $\xi_{x/y}$=+5/+5





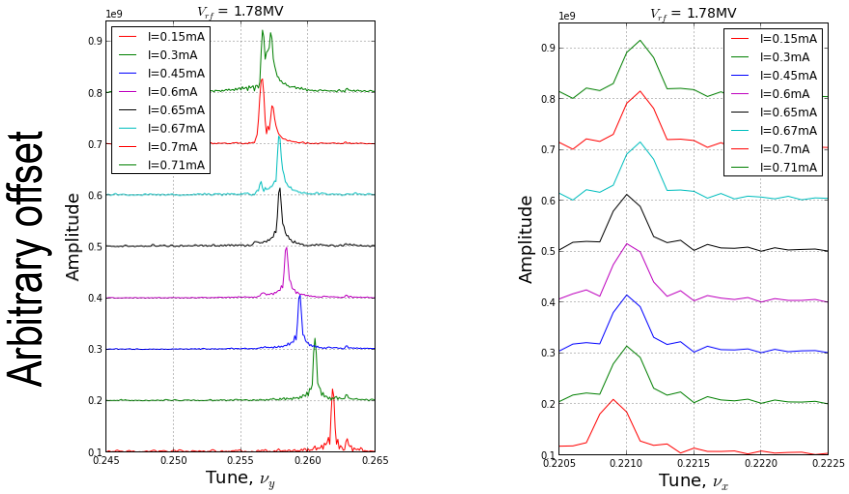
Effect of 4IVU's on Instability Threshold

3 DW's Magnet Gap Open ($\sigma_s = 3.4mm$)

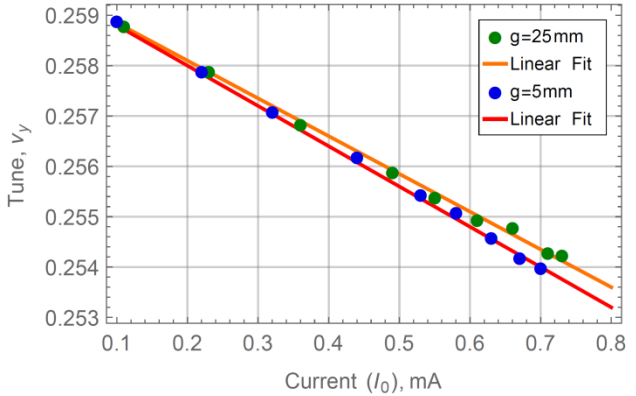
Apr. 15, 2015

Apr. 22, 2015

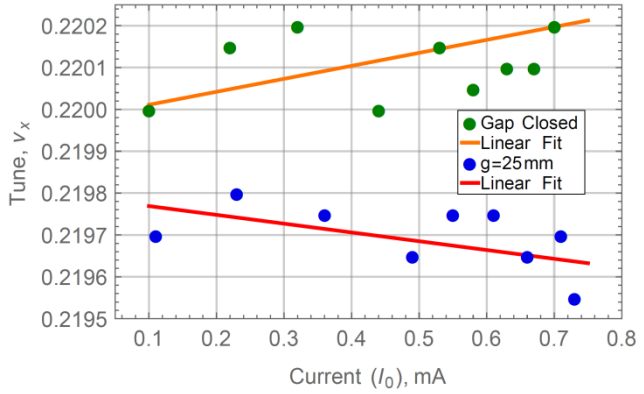
Chromaticity zero, I_{th}= 0.71mA



Spectra of BPM 41 vertical and horizontal TbT



Vertical Tune Shifts vs. Single-Bunch Current

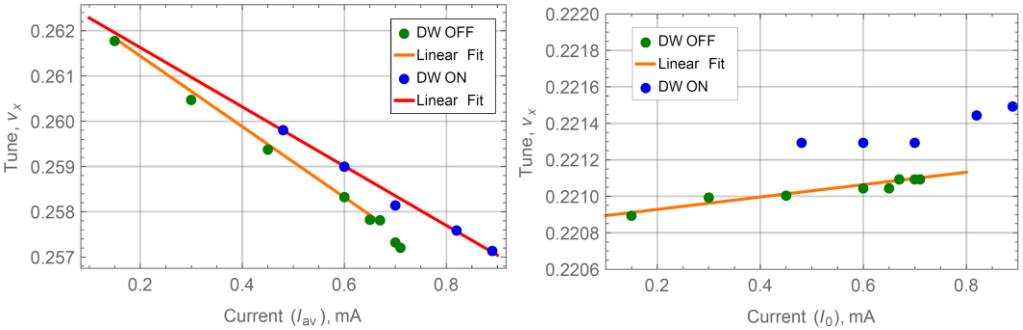


Horizontal Tune Shifts vs. Single-Bunch Current

- Accuracy of TbT tune measurements is 1x10^{-4}
- Measured contribution of 4IVU's to the total vertical kick factor is ~1.5kV/pC/m.
- 3IVU's located in Short-Straight Section ($\tilde{\beta}_x = 3.7m$, $\tilde{\beta}_y = 4.3m$) and 1IVU in Long-Straight Section ($\tilde{\beta}_x = 21m$, $\tilde{\beta}_y = 5m$)

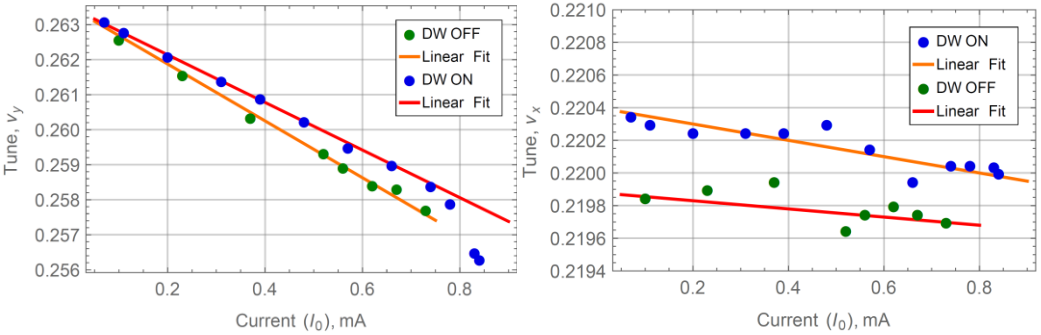
Contribution of 4IVU's to the Total Impedance

4IVU's Gap Closed



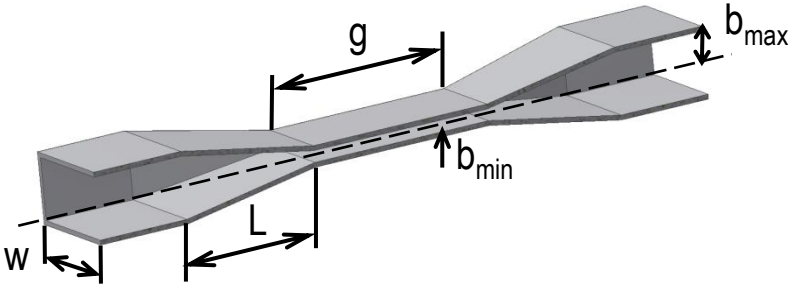
- Vertical Plane: I_{th}=0.71 with DW OFF, I_{th}=0.95 with DW ON
- Horizontal Positive Tune Shifts due to Quadrupole Impedance. Collimator Type Structure .

4IVU's Gap Open (g=40mm)



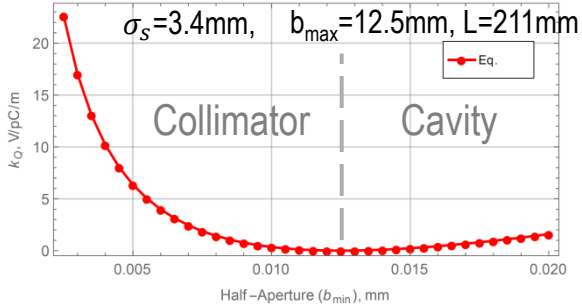
- Vertical Plane: I_{th}=0.73 with DW OFF, I_{th}=0.85 with DW ON
- Horizontal Negative Tune Shifts. Cavity Type Structure.

- In inductive regime for a case of a slow rectangular taper, $\theta \ll 1$ (G. Stupakov)



- Quadrupole Kick Factor (w >> b_{min})

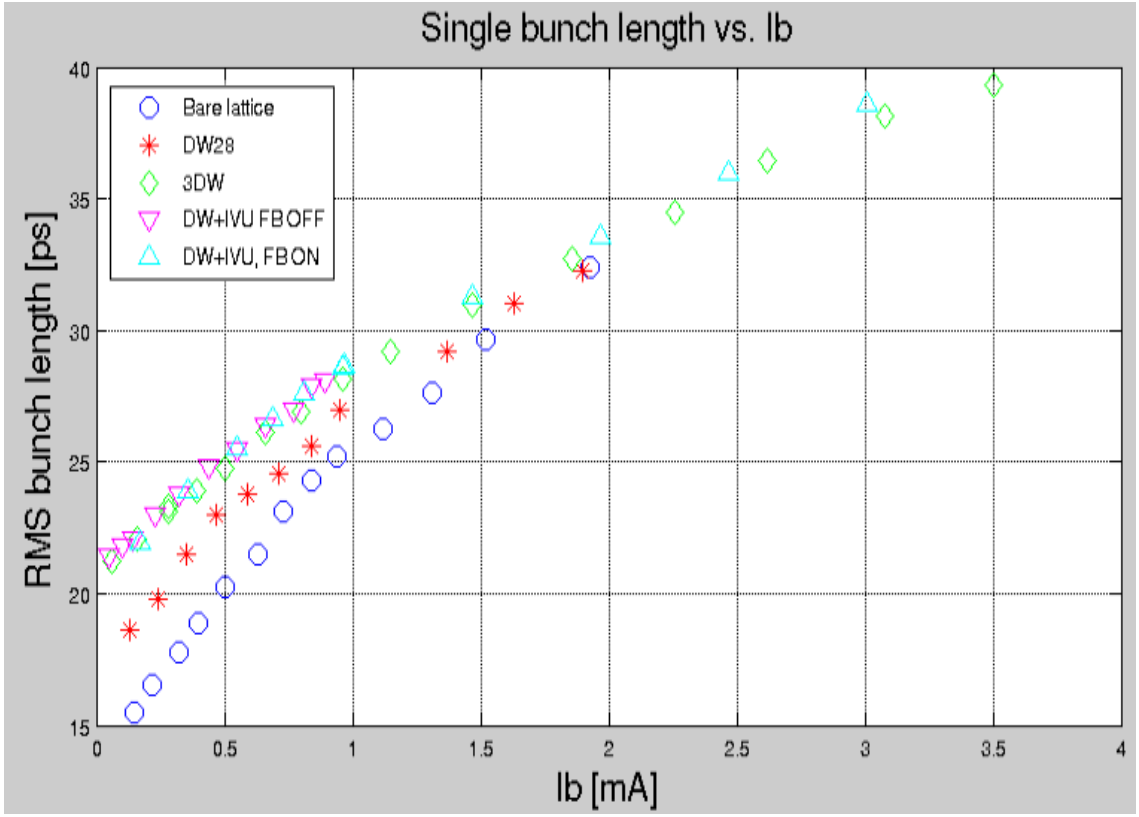
$$k_Q = \frac{Z_0 c}{2\sqrt{\pi}\,\sigma_s}\,\frac{\theta}{2\pi\, b_{min}}\left(1 - \frac{b_{min}}{b_{max}}\right)$$



- k_Q does not depend on width for w >> b_{min}

4IVU's Gap Closed: k_Q =74 V/pC/m

Bunch Lengthening Measurements

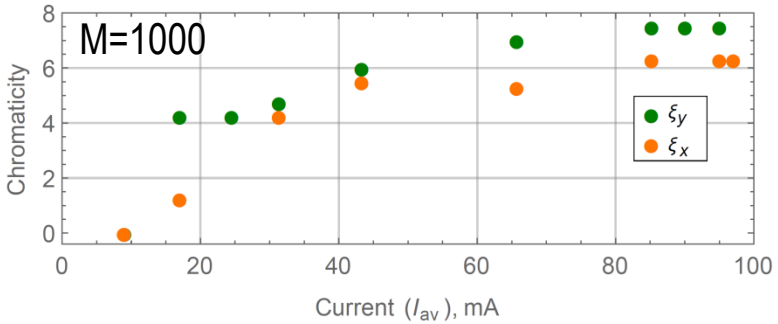


Bare Lattice: 4IVU's, 3DW's and 1EPU Magnet Gap Open

W. Cheng

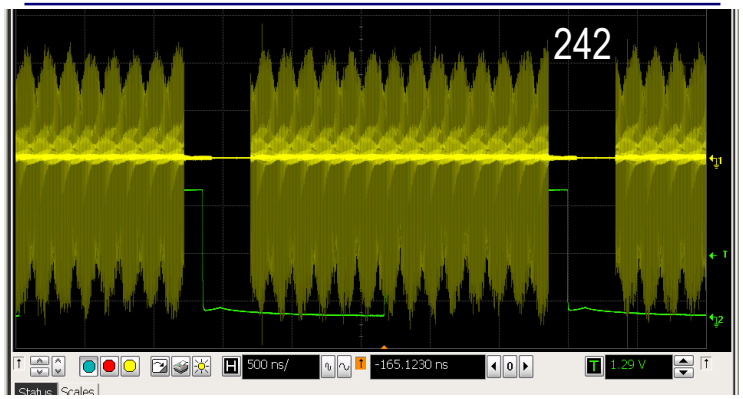
Coupled-Bunch Instability Threshold Analysis

3DW's and 4IVU's magnet gaps open



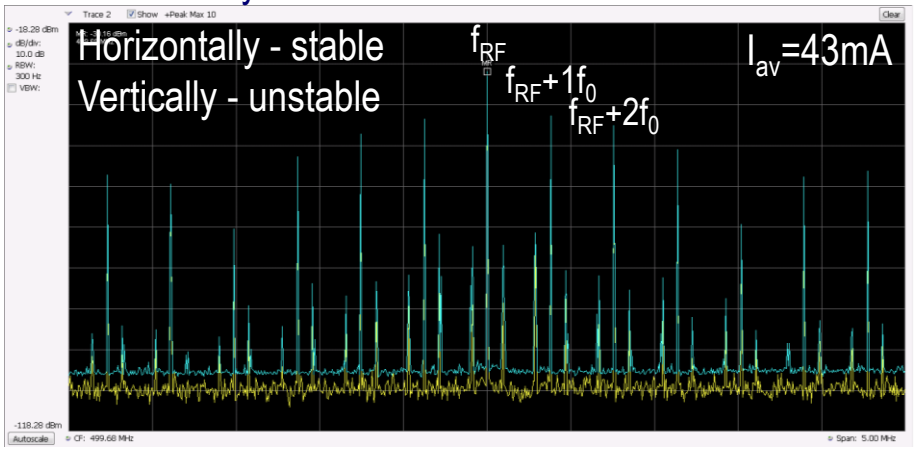
Coupled-Bunch Instability Threshold vs. Chromaticity

One Bunch Train with M=1000 Bunches



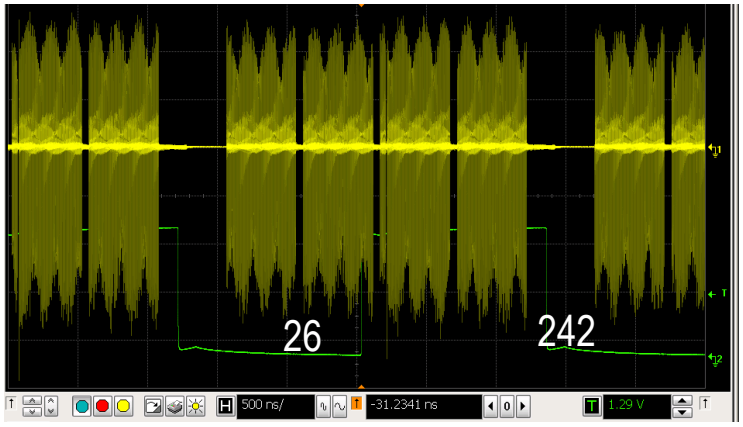
- Bunch is stable at chromaticity +6/+5 (Iav=43mA)

Chromaticity: +5/+5 M=1000



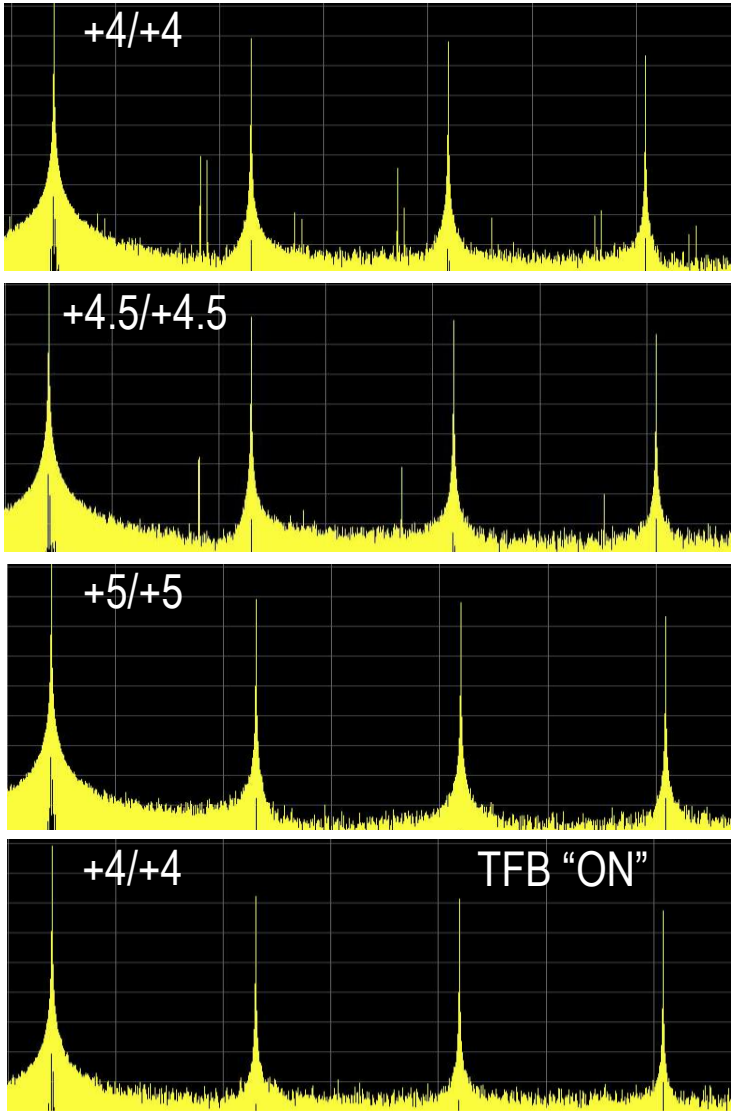
Frequency Spectrum from Network Analyzer

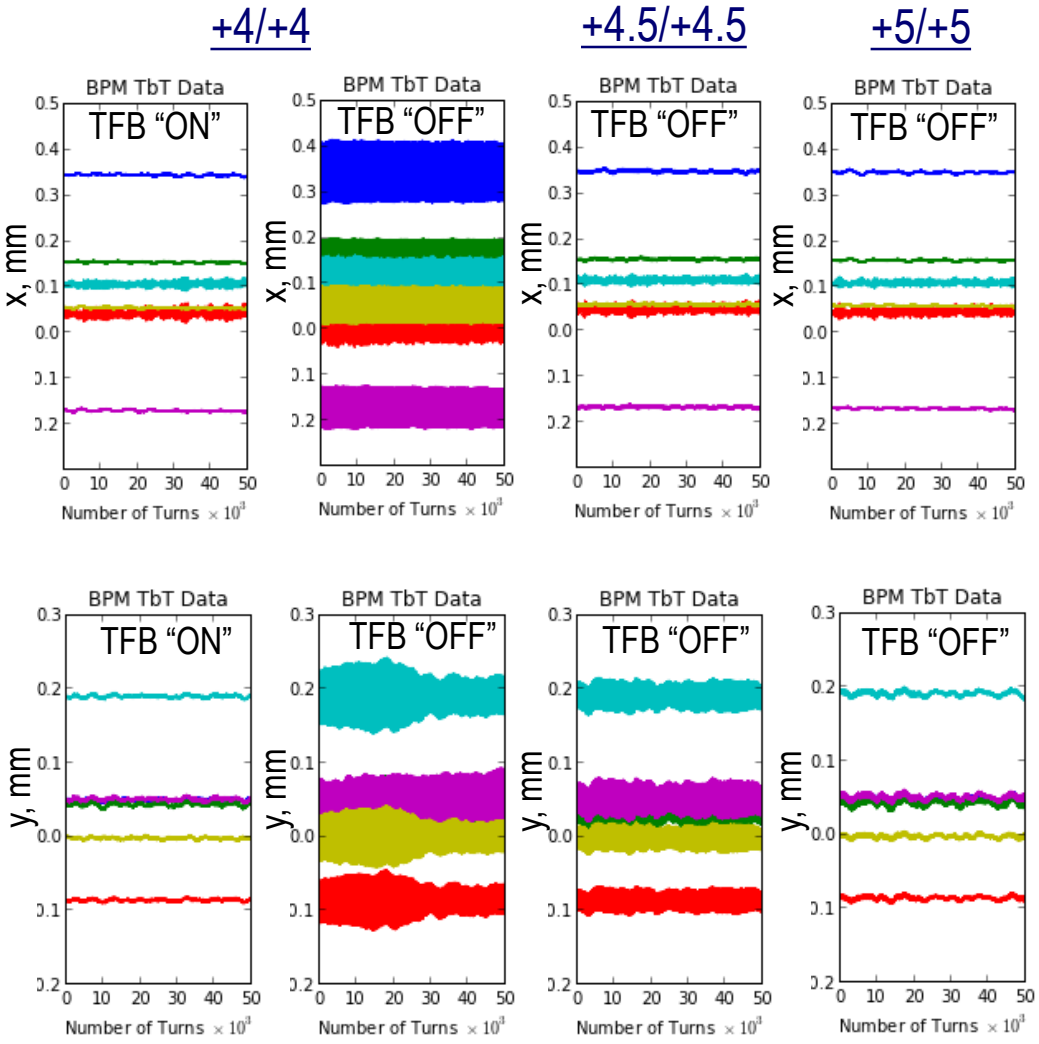
Four Bunch Train with M=4x250 Bunches



- Bunch is stable at chromaticity +4.5/+4 (Iav=43mA)

Average Current Iav=31.4mA (M=1000)

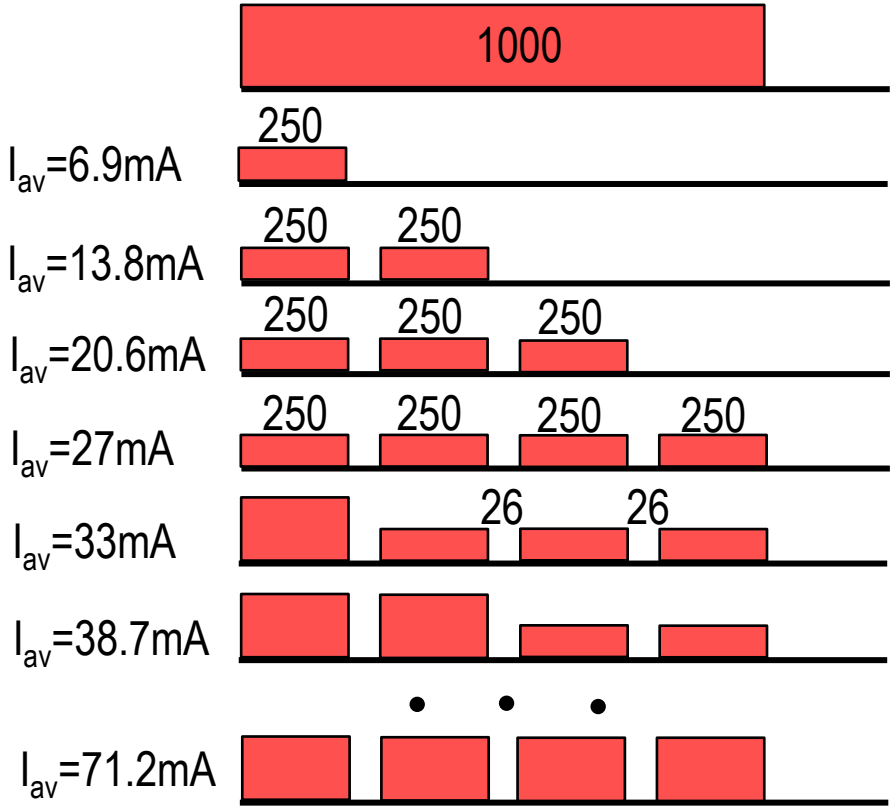




- Residual Oscillations

Current Dependent Tune Shifts

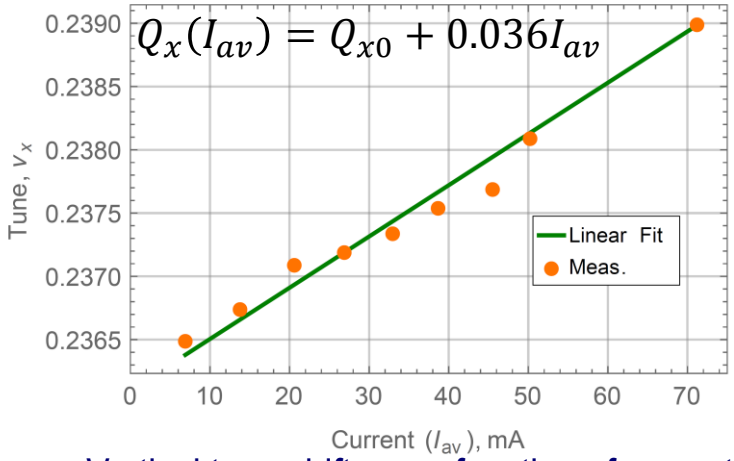
- Harmonic Number: h=1320 Apr. 8, 2015



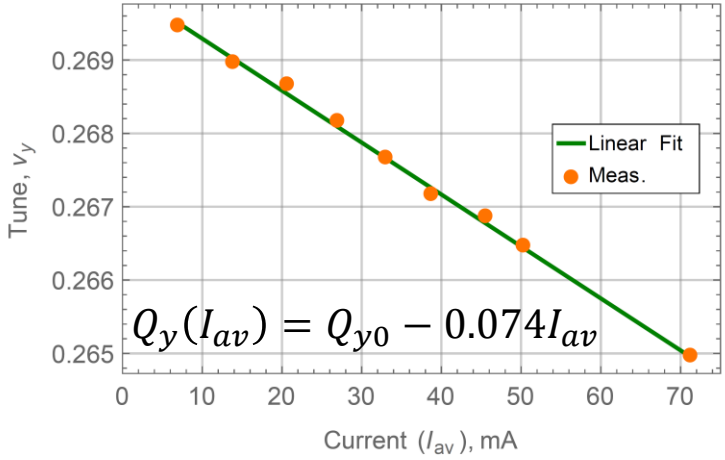
$$\Delta Q_y \approx -2\Delta Q_x$$

	Horizontal, A^{-1}	Vertical, A^{-1}
Tune Slopes	+0.036	-0.074

- DW's and IVU's magnet gap open



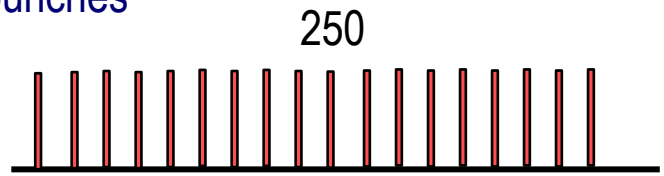
Vertical tune shifts as a function of current



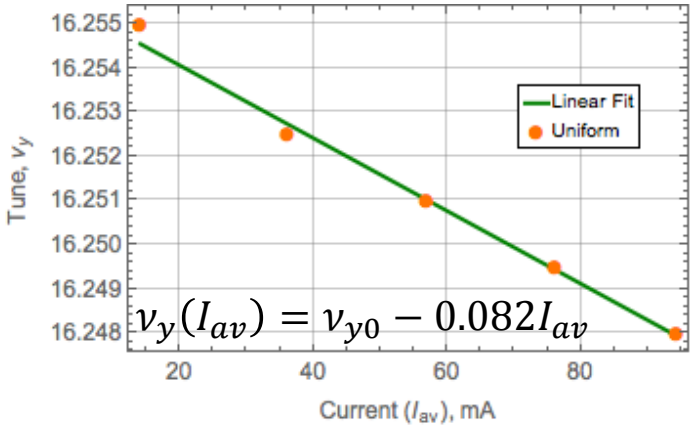
Horizontal tune shifts as a function of current

Current Dependent Tune Shifts (Cont.)

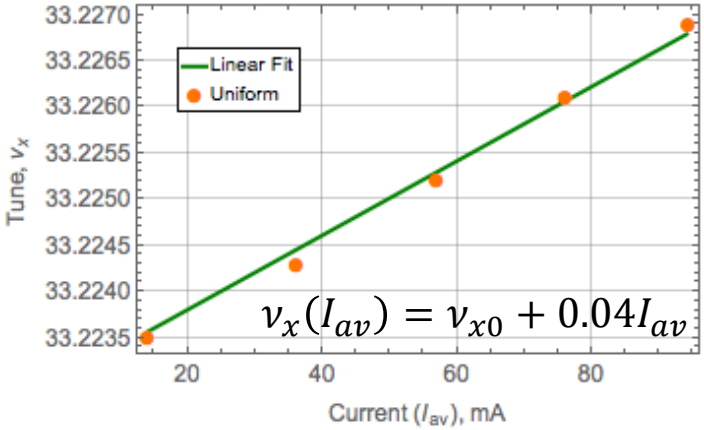
- DW's and IVU's magnet gap open
- Injected 250 equally spaced bunches
- Tune slopes do not depend on fill-pattern



Apr. 15, 2015



Vertical tune shifts as a function of current



Horizontal tune shifts as a function of current

$$\Delta Q_y \approx -2\Delta Q_x$$

	Horizontal, A^{-1}	Vertical, A^{-1}
Tune Slopes	+0.040	-0.082

Summary

- Beam intensity increasing continue. Single bunch (0.5mA) and average current (500mA) goals are achievable.
- Increasing the average current up to 300mA in 2015 with the final goal of 500mA in 2016
- ID's integration in progress
- Continue to measure change in impedance due to ID's
- Stabilizing effect of positive chromaticity, +7/+7. The single bunch threshold current is I_{th}=6mA
- Stabilizing effect of TFB System on single bunch intensity
- Special attention to heating of the vacuum components due to beam intensity increasing.
- We plan to use third-harmonic cavities to lengthen bunches and provide Landau damping

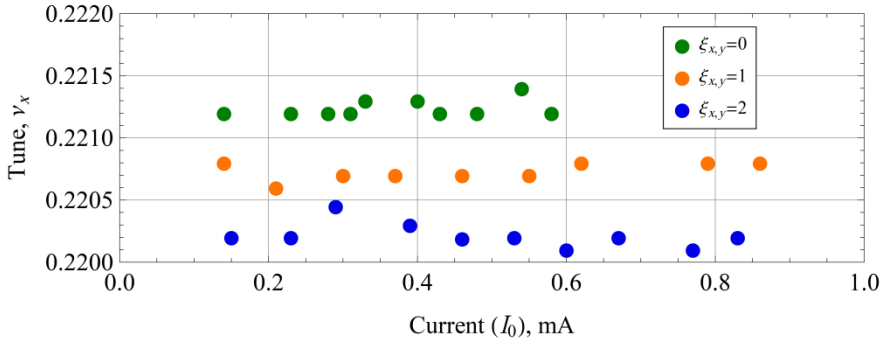
Acknowledgments

- **NSLS-II/BNL/US:**

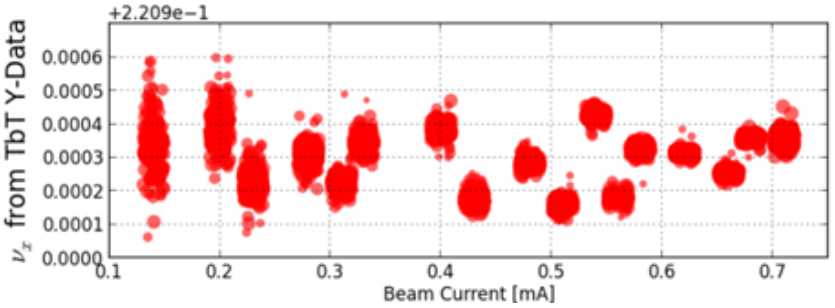
  B. Kosciuk, C. Hetzel, H.-C. Hseuh, B. Bacha, W. Cheng, F. Willeke, T. Shaftan, G. Bassi, G. Wang, S. Ozaki, Y. Li, L.-H. Yu, Y. Hidaka, J. Choi, L. Yang, O. Singh, V. Smalyuk, E. Blum, B. Podobedov, R. Smith, T. Summers, J. Rose, F. Gao, S. Seletskiy, X. Yang, W. Guo, Y. Bengtsson, E. Zitvogel, T. Tanabe.

Back-Up Slides

Horizontal Plane (Single Bunch) w/o IVU's



Horizontal Tune vs. Current for high Resolution FFT Method

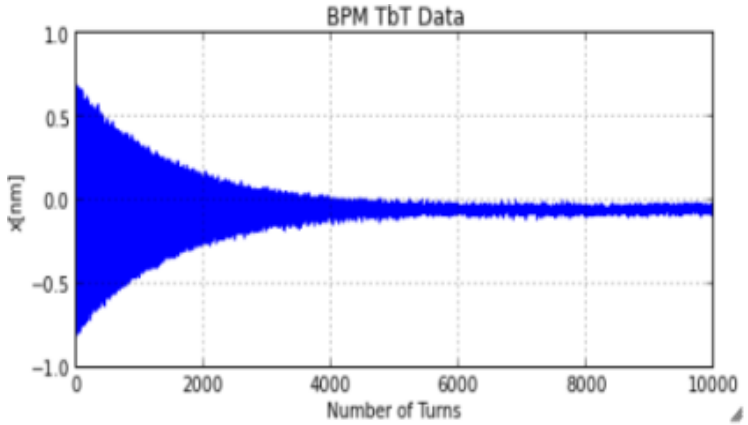


Horizontal Tune vs. Current for Interpolated FFT Method for all 180 BPMs **Y. Hidaka**

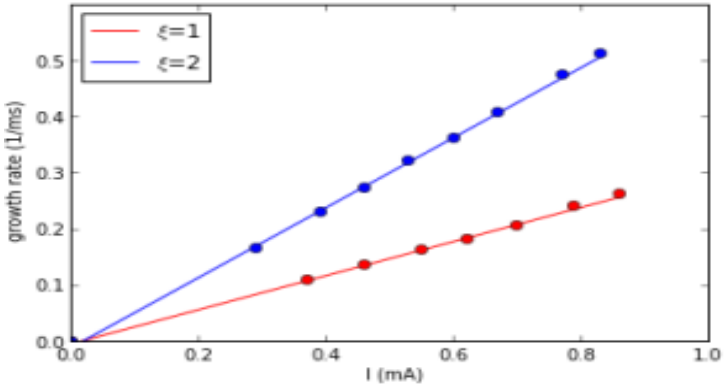
Broad-Band Resonator **G. Bassi**

$\omega_r = 2\pi \times 30GHz$

$Q = 1 \qquad R_{sh,x} = 0.4M\Omega/m$



Measured horizontal TBT data at chromaticity $\xi_{x,y} = +1/+1$, BPM 6 ($I_0 = 0.85\ mA$).



Absolute value of the measured horizontal growth rate as a function of current at $\xi_{x,y} = +1/+1$ and $\xi_{x,y} = +2/+2$ with the fitted slope.