First Collective Effects Measurements in NSLS-II

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Sep. 17-19, 2014

Low Emittance Rings 2014 Workshop
(LOWεRING 2014)

U.S. DEPARTMENT OF ENERGY | Office of Science

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Outline

- Phase 1 (25mA / PETRA-III) and Phase 2 (50mA / CESR-B) Commissioning w/o ID's
- Local Beam Impedance Measurements
- First Collective Effects and Beam Impedance Measurements
- Summary

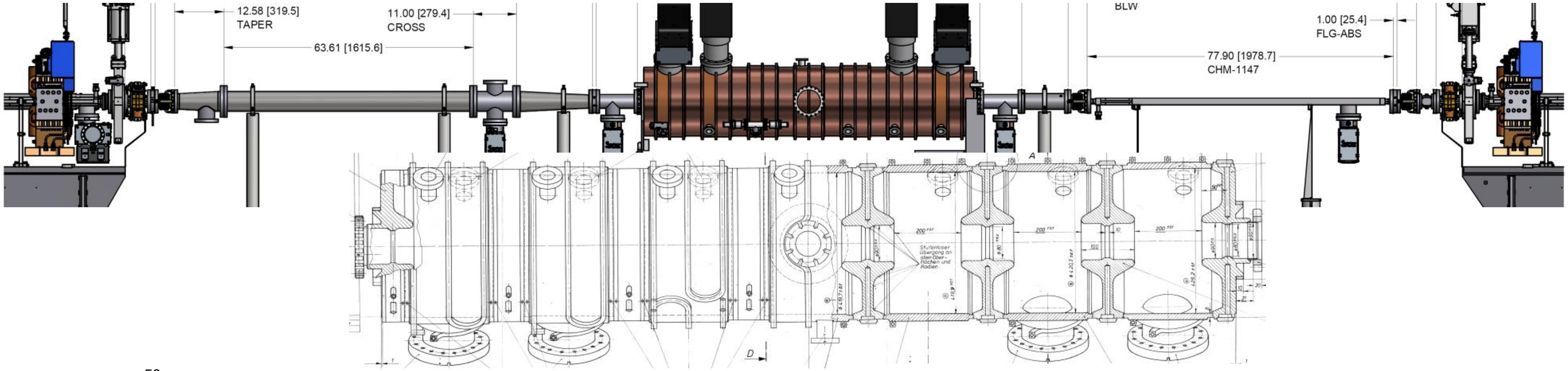
NSLS-II Parameters

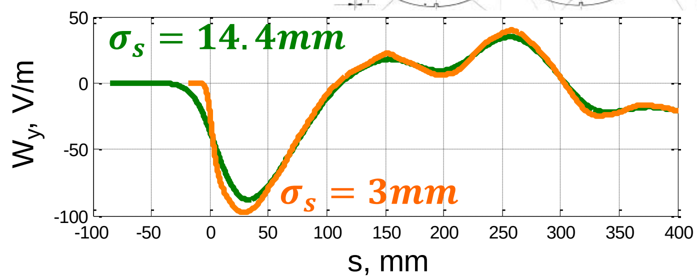
NSLS-II Machine Concept

- Superconducting RF
- Top-Off Operation
- DBA30 Lattice
- Ultra-Low Emittance (<1 nm)
- Damping Wigglers
- Large Dipole Bend Radius (25 m)
- Provision for IR Source
- Three-pole wiggler x-ray sources

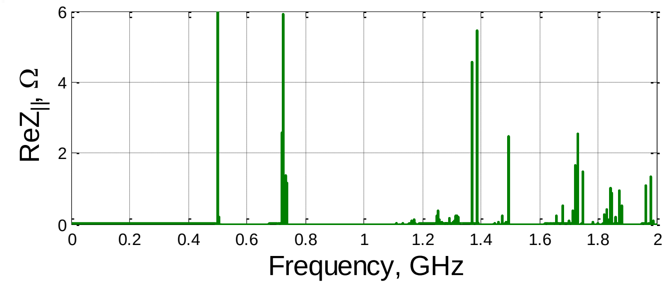
Energy	3.0 GeV	**Energy Spread**	0.094%
Circumference	792 m	**RF Frequency**	500 MHz
Number of Periods	30DBA	**Harmonic Number**	1320
Length Long Straights	6.6 & 9.3m	**RF Bucket Height**	3%
Emittance (h,v)	<1nm, 0.008nm	**RMS Bunch Length**	15ps
Momentum Compaction	.00037	**Average Current**	500mA
Dipole Bend Radius	25m	**Current per Bunch**	0.5mA
Energy Loss per Turn	<2MeV	**Charge per Bunch**	1.2nC

RF Straight Section (PETRA-III, Cell24)

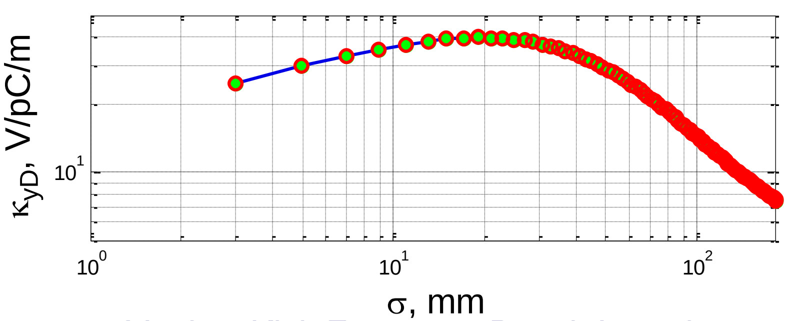




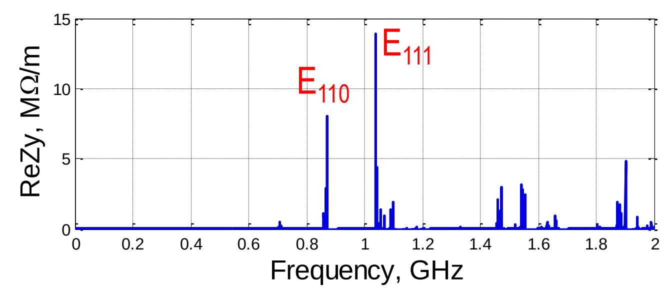
Vertical Dipole Short-Range Wakepotential



Real Part of the Longitudinal Impedance



Vertical Kick Factor vs. Bunch Length



Real Part of the Transverse Impedance

Longitudinal Coupled-Bunch Instability

- Measured CB Instability driven by PETRA-III HOM's

Frequency MHz	Bunch Mode	Average Current mA	Cavity Temperature C°
1374	991	10	38.4
728	603	11.64	39.2

- Calculated PETRA-III Higher-Oder Longitudinal Modes

Shunt Impedance, $R_{sh,\|\|}$	Frequency, f, MHz	Quality Factor, Q_0
0.6	1374	36000
3	728	33600

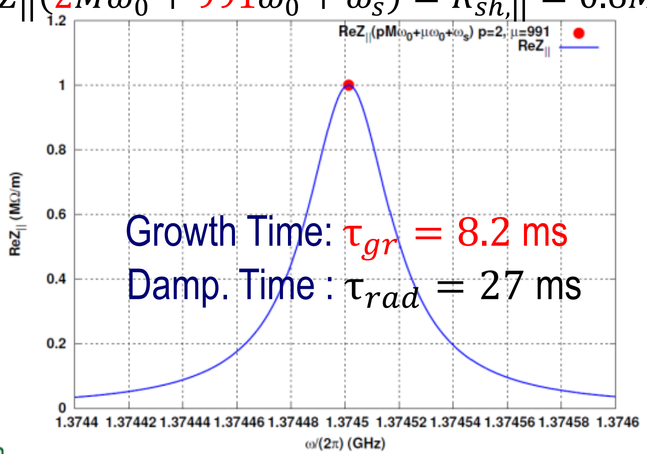
- Growth rates for 1320 bunches uniformly filling the ring:

$$\frac{1}{\tau_\mu} = -\frac{I_0\eta}{4\pi E_0\nu_s}\sum_{p=-\infty}^{+\infty}(pM\omega_0+\mu\omega_0+\omega_s)e^{-(pM\omega_0+\mu\omega_0+\omega_s)^2\sigma^2}ReZ_{||}(pM\omega_0+\mu\omega_0+\omega_s)$$

Worst Case Scenario

Frequency Set to : $f_r = 1374.5\ MHz$

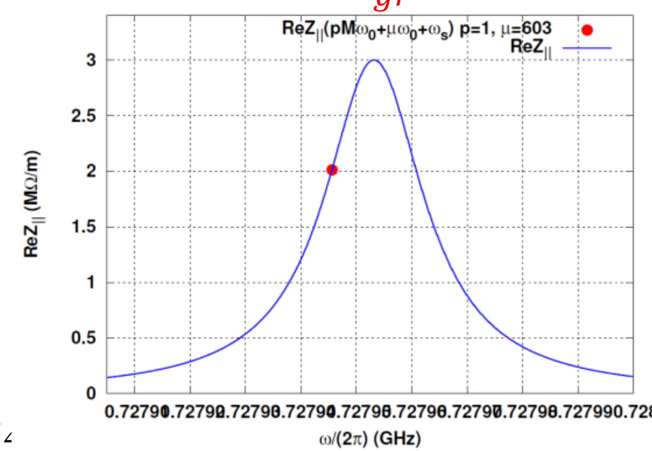
$$ReZ_{||}(2M\omega_0 + 991\omega_0 + \omega_s) = R_{sh,||} = 0.6M\Omega$$



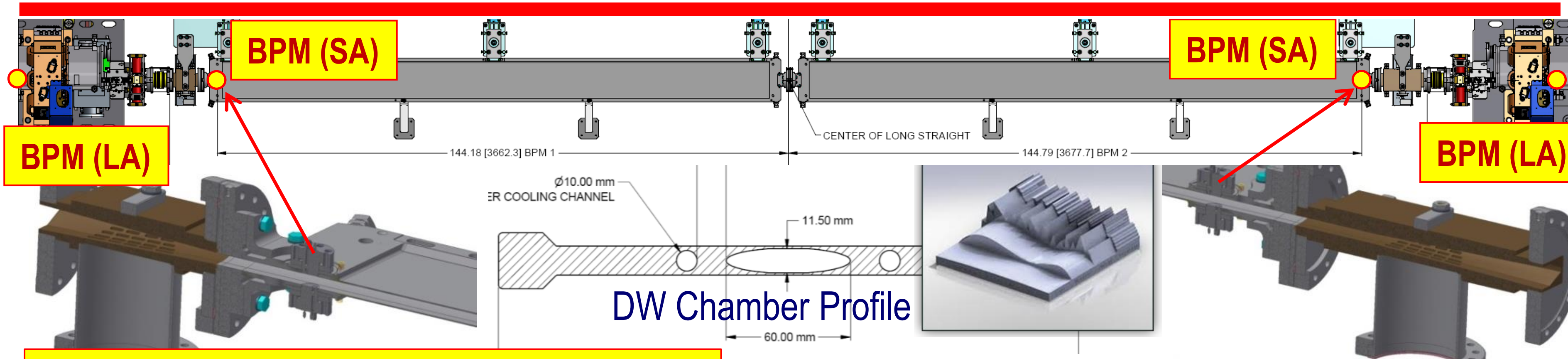
Matching To Measured Growth Time

Frequency Set to : $f_r = 727.964\ MHz$

Growth Time: $\tau_{gr} = 6.7$ ms



NEG Coated DW Chamber (Cell 8)

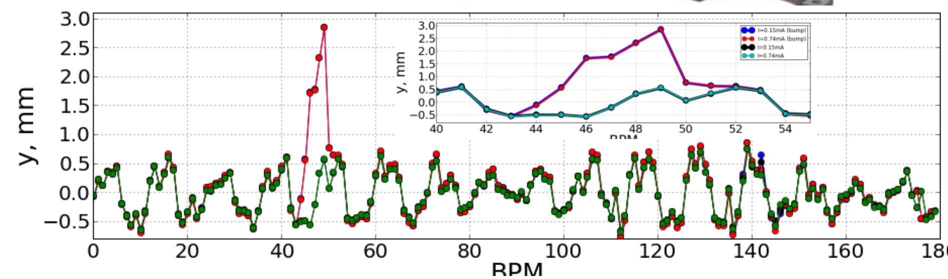


- NEG coating long. surface roughness: $< 1\mu m$

Table 1: Numerically Obtained Data ($\sigma_s = 3mm$)

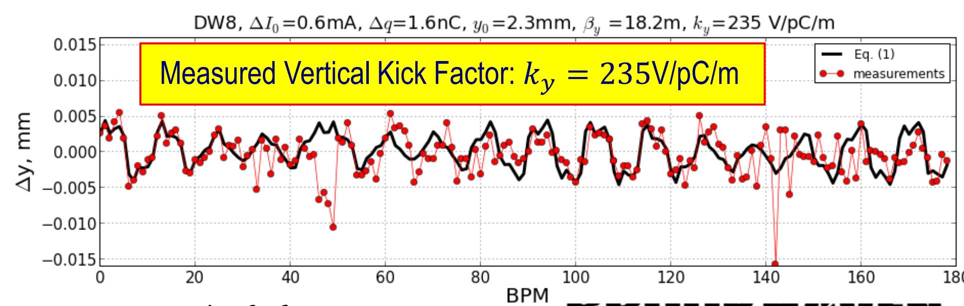
	k_{yrw}, V/pC/m	k_{yD}, V/pC/m	k_{yQ}, V/pC/m
Fast Corr.	1.36	-	-
BLW	0.14	0.63	0.28
SA BPM	1.36	TBD	TBD
DW Chamber	114 (Al)	40.8	7.1
SA BPM	1.36	TBD	TBD
BLW	0.14	0.63	0.28
Fast Corr.	1.36	-	-

Straight Section (Cell08): $k_{yT} = 170$ V/pC/m

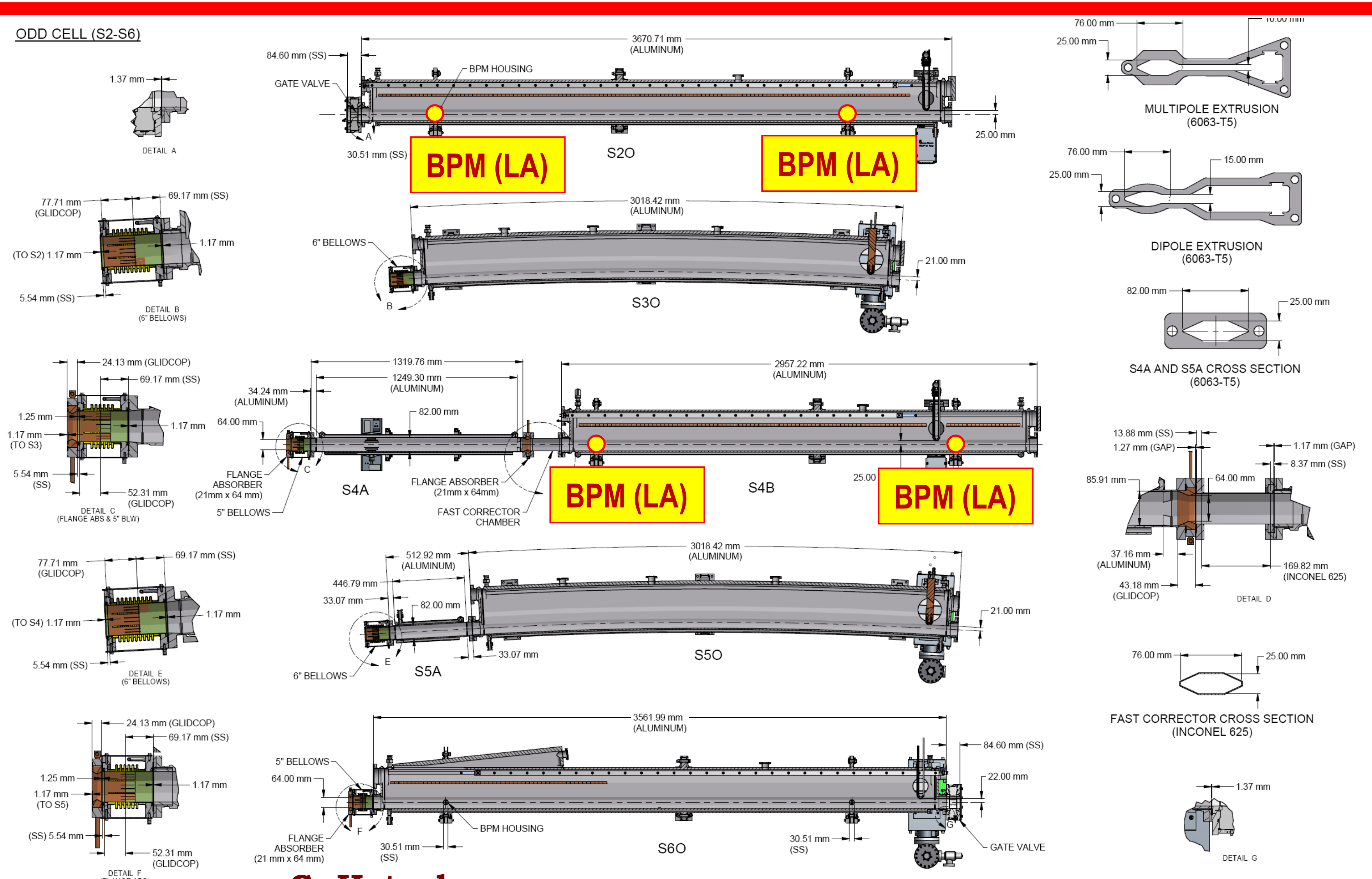


V. Kiselev and V. Smaluk, "Measurement of Local Impedance by an Orbit Bump Method", NIMA 525 (2004), 433-438.

$$\Delta y(s) = \frac{\Delta q}{E/e} k_{\perp} y_0 \frac{\sqrt{\beta_y(s_0)\beta_y(s)}}{2\sin \pi\nu_y} \cos\left(|\mu(s) - \mu(s_0)| - \pi\nu_y\right) \quad (1)$$



Odd Cell (Standard Arc)



C. Hetzel

Low Emittance Rings 2014 Workshop

Transverse Mode Coupling Instability

- Average Transverse Coherent Tune Shift (Vanishing Chromaticity)

$$\left(\frac{\Delta\nu_y}{\nu_s}\right)^{av} = \frac{e^2 N_e \beta_y}{4\pi\,\gamma\, mc^2 \nu_s} k_y = 0.7$$

- Vertical Kick Factor (Geometric)

$$k_y = \frac{c}{\pi}\int_0^\infty dk\, ImZ_y(k) e^{-k^2\sigma^2}$$

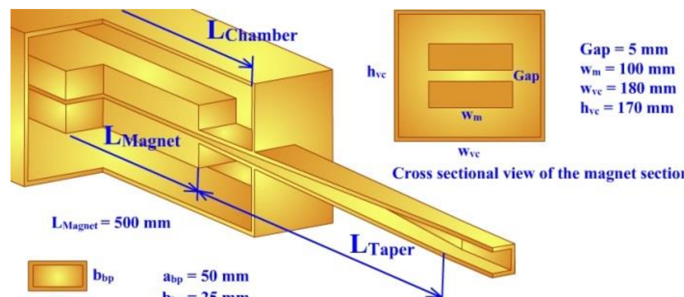
- Broad-Band Resonator

$$k_y^{BBR} = \frac{c}{2\sqrt{\pi}\sigma_s}\frac{R}{Q} \qquad (k_r\sigma_s > 1)$$

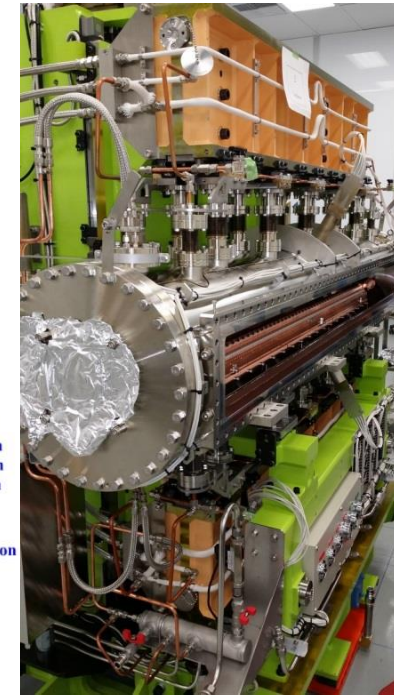
- Resistive Wall (Normal Conducting)

$$k_y^{rw} = 0.58\frac{cZ_0}{4\pi}\frac{2s_0 L}{b^4}\sqrt{\frac{s_0}{\sigma_s}}$$

$$s_0 = \left(2b^2 / Z_0\sigma_{cond}\right)^{1/3}$$



$k_y = 425\, V/pC/m$



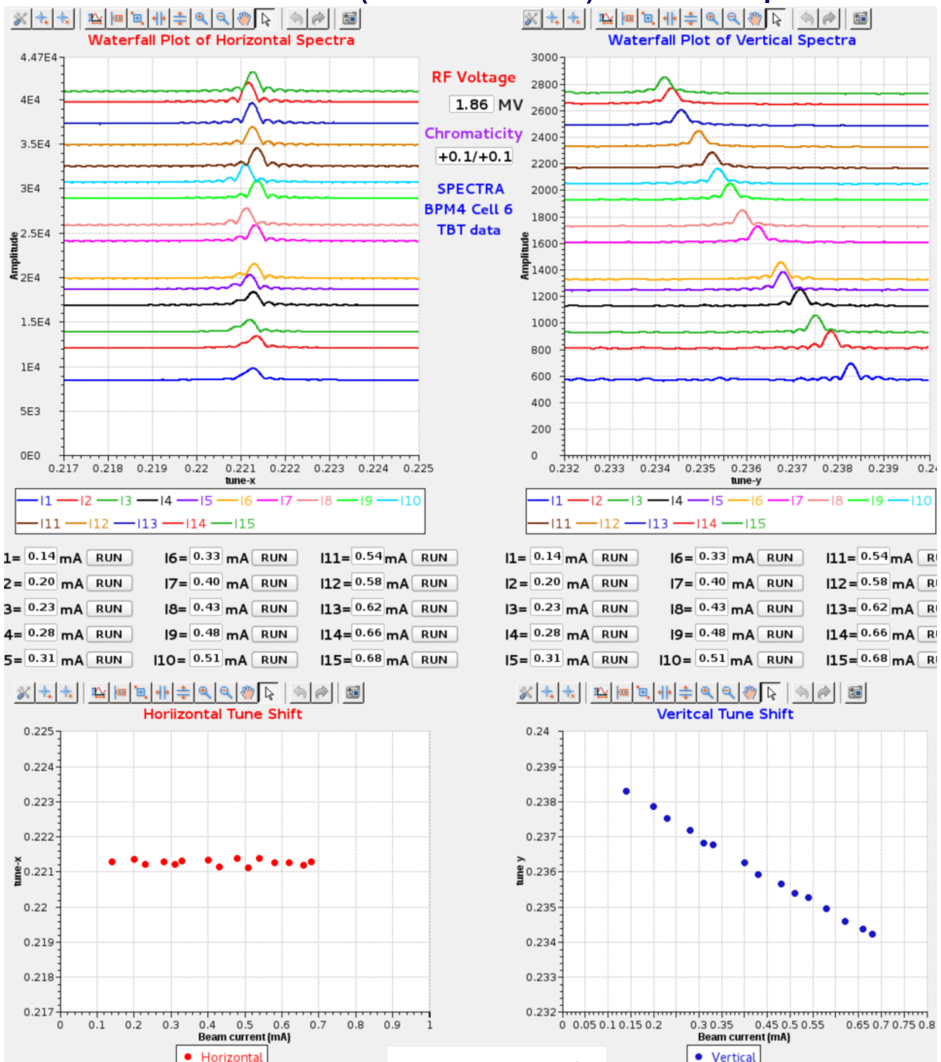
Bunch Length,	$\sigma_s = 3mm$
Bunch Charge,	$Ne = 1.25nC$
Energy,	$E = 3GeV$
Synchrotron Tune,	$\nu_s = 0.009$
TMCI Threshold,	$k_y\beta_y < 180\, kV/pC$

20 ID's with 2.5mm radius
70m of Cu & $\beta_y = 3m$
$k_y\beta_y = 49kV/pC$
$I_{th} = 1.8mA$ per bunch

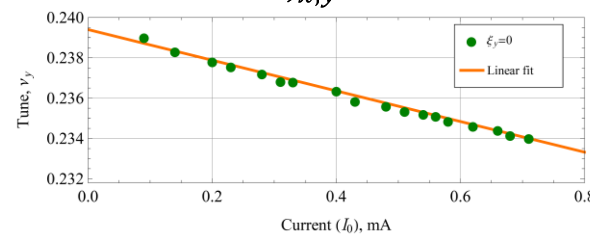
A. Blednykh et al., "Transverse Impedance Of Small-Gap …, EPAC06
S. Krinsky, " Simulation of Transverse Instabilities …, BNL-75019-2005-IR

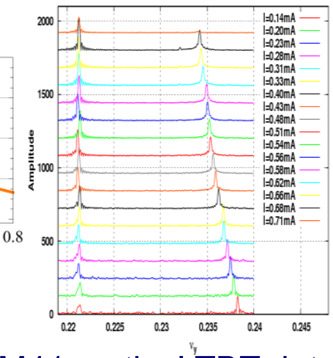
Phase 1, Vertical Plane (Vanishing Chrom.)

- On-Line Plot (CSS-Panel) of the Spectra



$\xi_{x,y} = 0$





Vertical Tune and Spectra of BPM41 vertical TBT data

- Accumulated Single Bunch Current: $I_0 = 0.7\text{mA}$

Measured Vertical Kick Factor

$$k_y = \frac{\Delta\nu_y}{\Delta I_0}\frac{2E_0\omega_0}{\beta_y} = 14\ kV/pC/m$$

Energy,	$E_0 = 3GeV$
RF Voltage,	$V_{RF} = 1.86MV$
Bunch Length,	$\sigma_s = 3.3\text{mm}$
Beta Function,	$\beta_y = 7.7\text{m}$
Rev. Frequency,	$\omega_0 = 2\pi \times 378.6\text{kHz}$

A. Blednykh et al., "NSLS-II Commissioning with 500MHz …", IPAC14

Resistive Wall Evaluation (σ_s=3mm)

	Length, mm	$\sum k_{loss}$, V/pC	$\sum k_y$, kV/pC/m	$\sum k_y \beta_y$, kV/pC
Long Straight Sections	129839.18	2.2 (3.3)	0.52 (1.2)	3 (6.7)
Short Straight Sections	89256.6	1.3	0.15	1.1
Even Arcs	286465.76	3.5	0.41	7.1
Odd Arcs	286381.14	3.5	0.4	7.2
Total:	**791942.7**	**10.5 (11.6)**	**1.48 (2.15)**	**18.4 (22.1)**

- Loss Factor

$$k_{loss} = 1.2 \frac{cZ_0}{4\pi} \frac{L}{2\pi b^2} \left(\frac{s_0}{\sigma_s}\right)^{3/2}$$

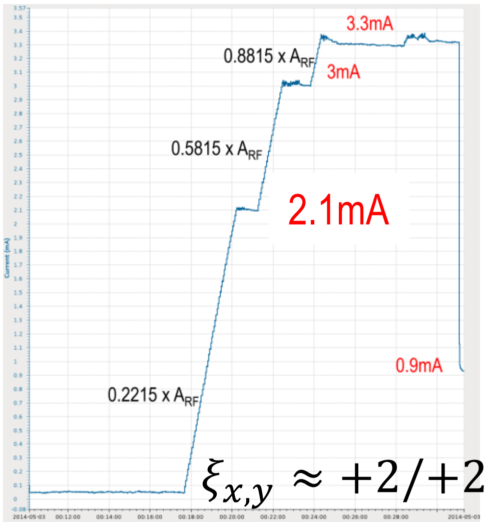
- Kick Factor

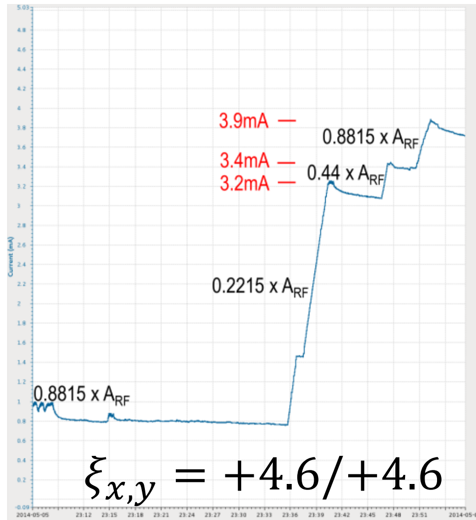
$$k_y = 0.58 \frac{cZ_0}{4\pi} \frac{2 s_0 L}{b^4} \sqrt{\frac{s_0}{\sigma_s}}$$

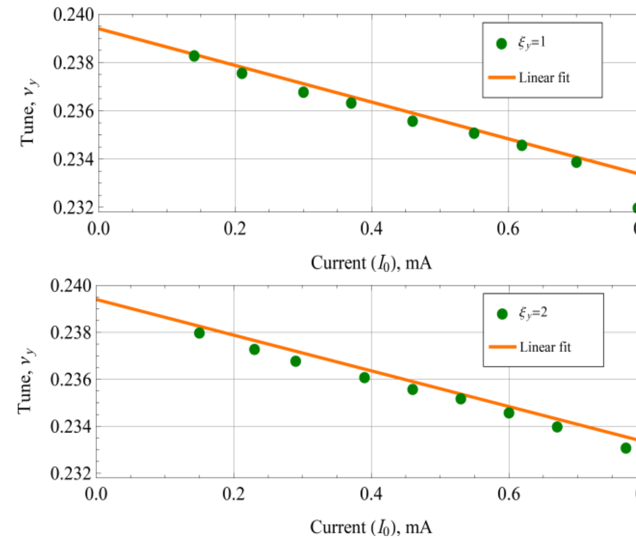
NSLS-II Circumference: 791.9589 m

Vertical Plane (Positive Chromaticity)

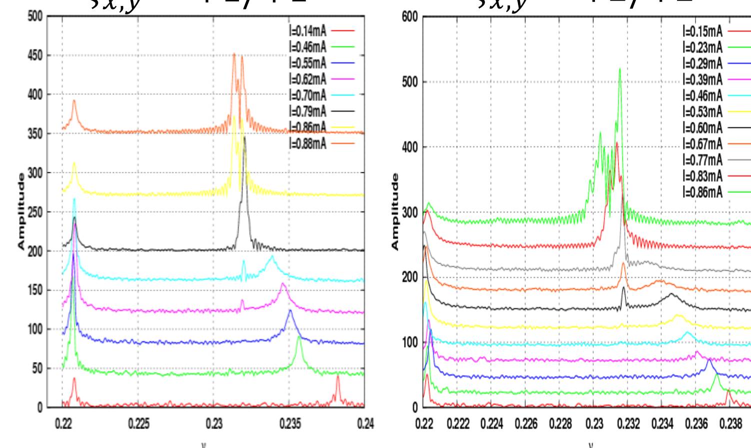
- High intensity due to lowering and ramping up V_{RF}
- Transverse bunch-by-bunch feedback system OFF





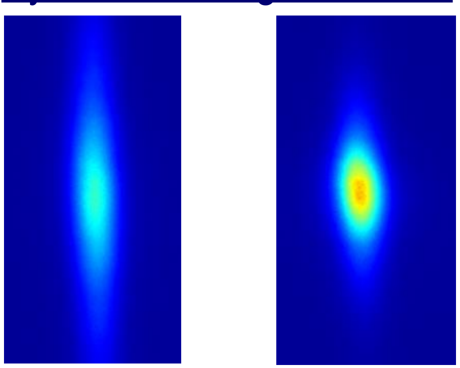


Vertical tune as a function of current



Spectra of BPM41 vertical TBT data.

Synchrotron Light Monitor



$I_0 = 0.96\text{mA}$ $\quad$ $I_0 = 0.7\text{mA}$

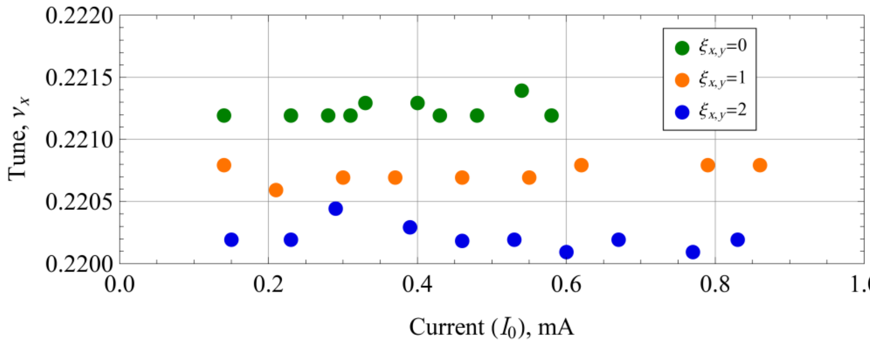
- Synchrotron Tune

$$\nu_s = \sqrt{-\frac{h\eta}{2\pi\beta_s^2 E_0} V_{RF} cos\phi_s}$$

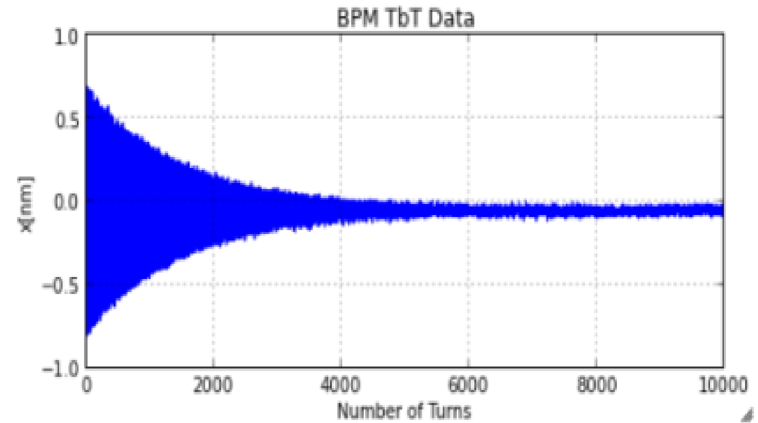
- Bunch Length

$$\sigma_s = \frac{\sqrt{2\pi}c}{\omega_0}\sqrt{\frac{-\eta E_0}{heV_{RF}cos\phi_s}}\frac{\sigma_\varepsilon}{E_0}$$

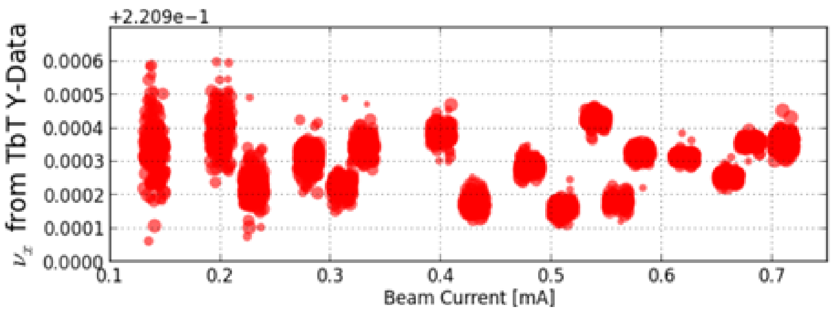
Horizontal Plane (Single Bunch)



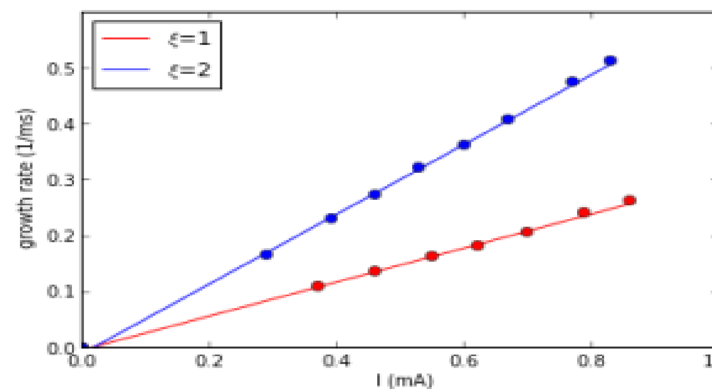
Horizontal Tune vs. Current for high Resolution FFT Method



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



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



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.

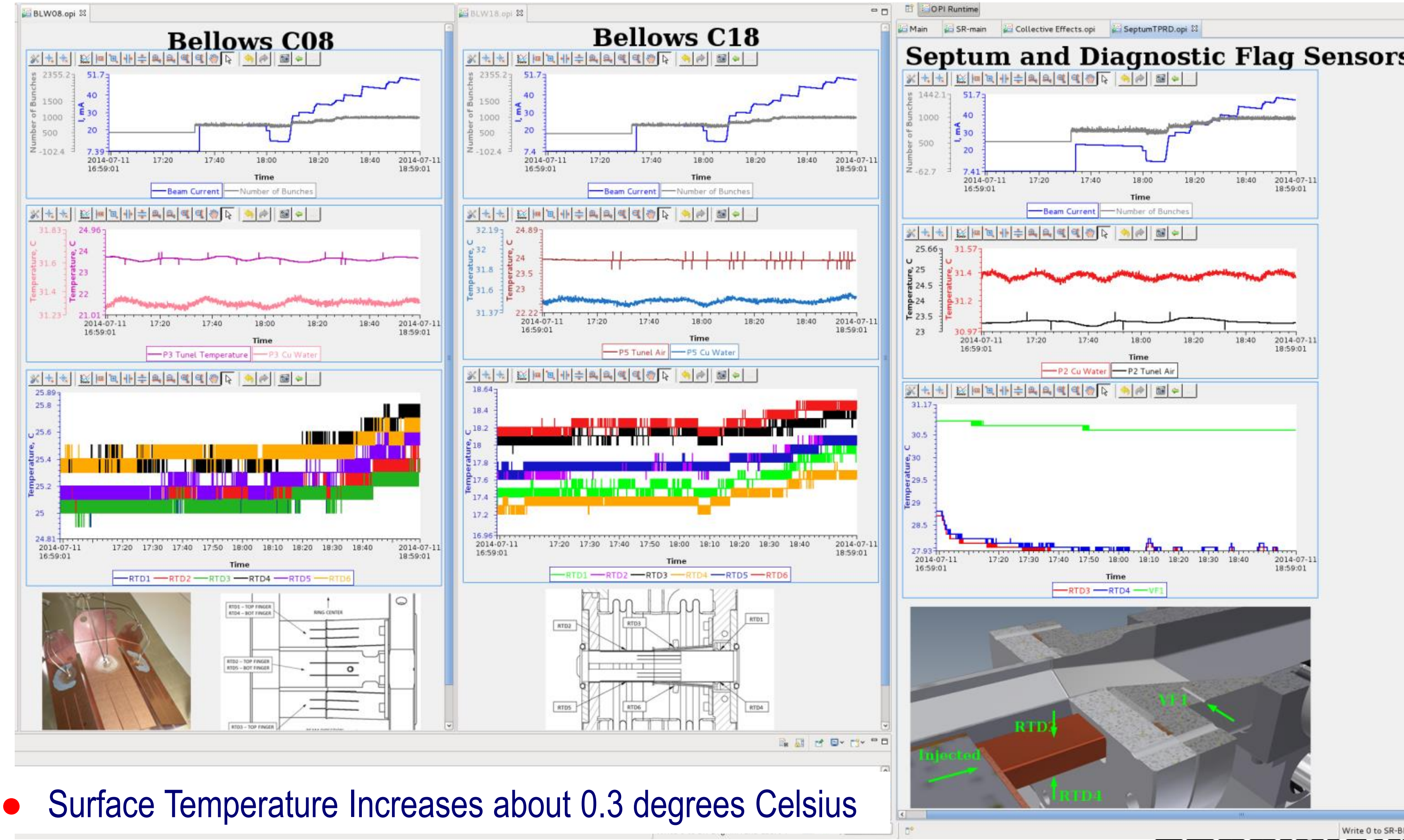
Broad-Band Resonator **G. Bassi**

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

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

Phase 2, Achieved a Stored Current of 50 mA

- Screenshot of the CSS-Panels (BLW C08, C18 & Septum)



- Surface Temperature Increases about 0.3 degrees Celsius

Summary

- NSLS-II storage ring commissioning continue
- Phase 3, ID's commissioning in under way
- Repeat local impedance measurements with modified local bump model for 4 straight sections occupied with NEG coated chambers, 3DW's and 1 EPU, and for several variable-gap IVU's
- Orbit Response Matrix Fit Method for Local Transverse Impedance Measurements is going to be applied
- Single bunch (0.5 mA) and average current (500 mA) goals are achievable

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, B. Podobedov, Y. Li, L.-H. Yu, Y. Hidaka, J. Choi, L. Yang

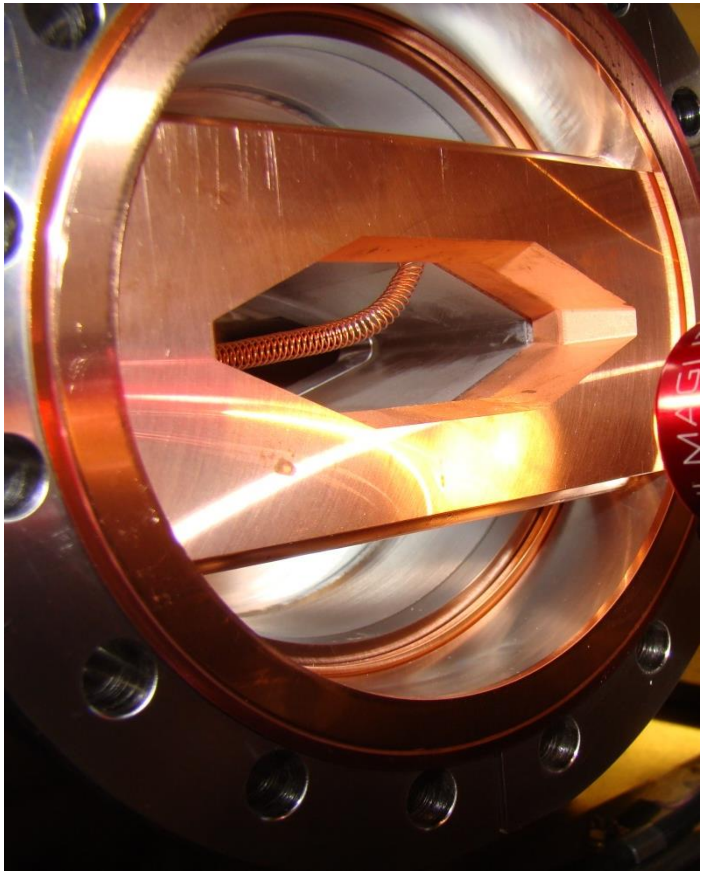
- **DIAMOND/UK**

  V. Smaluk

Back-Up Slides

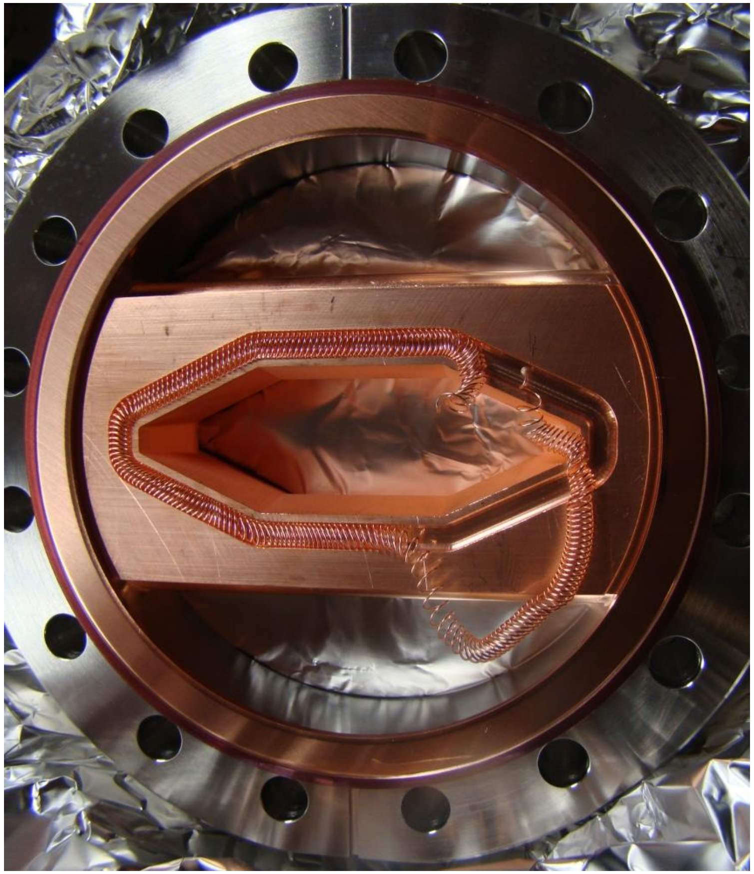
RF Spring – Aperture Limitation

- Phase 1 (Cell10)



Difficulties in Orbit Correction

- After Phase 1, 25mA (Cell08)

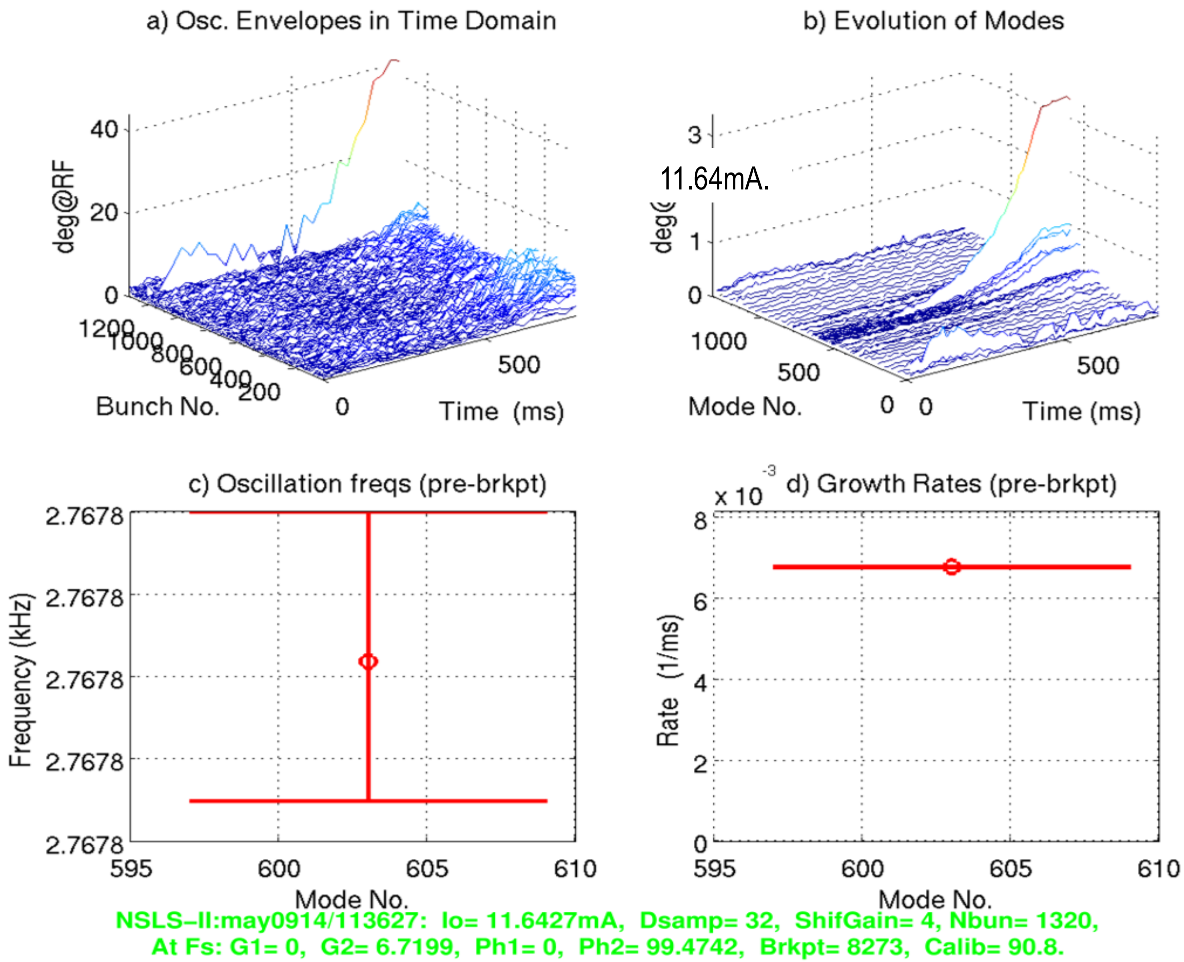


The fan burned through the spring

The assembly method needs to revised !

Commissioning Phase 1: Longitudinal Coupled-Bunch Instability Analysis

- Observed longitudinal instability in multi-bunch mode (~1000 bunches) by HOM with frequency $f_r = 728$MHz (bunch mode 603) with growth time $\tau_{gr} = 6.7$ms, much smaller than the longitudinal radiation damping time $\tau_s = 27$ms, at an average current $I_0 = 11.64$mA.



Courtesy of D. Teytelman

Transverse Coupled-Bunch Stability Analysis (I_{av}=25mA)

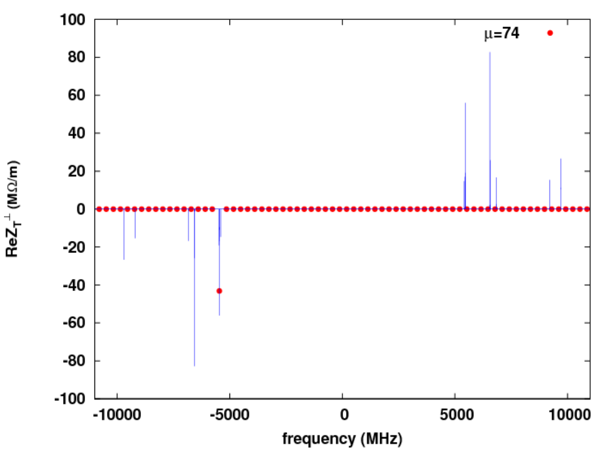
(Analysis performed prior to the commissioning)

Transversely **unstable** at zero chromaticity (ξ=0): growth time $\tau_{gr} = 0.74ms \ll \tau_x = 54ms$

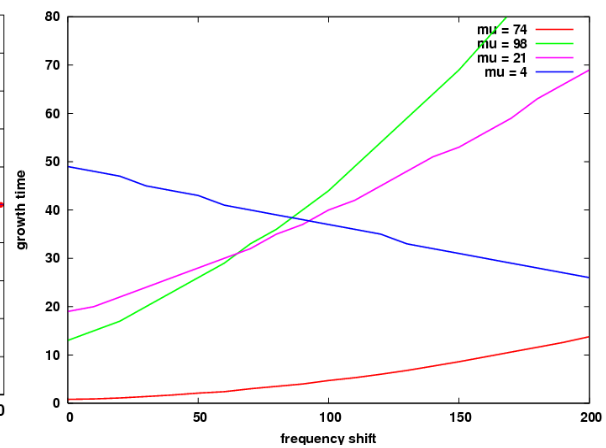
Cure: 1) Run at positive chromaticity to provide damping via slow head tail effect
2) Frequency shift (ΔΩ) of HOM's

$$\frac{1}{\tau} = \mathrm{Im}(\Omega_\mu - \omega_\beta) = -\frac{I_b M c}{4\pi (E_0/e)\upsilon_x} \sum_{p=-\infty}^{+\infty} \mathrm{Re}\, Z_\perp (pM\omega_0 + \mu\omega_0 + \omega_\beta).$$

Fastest growing mode μ=74

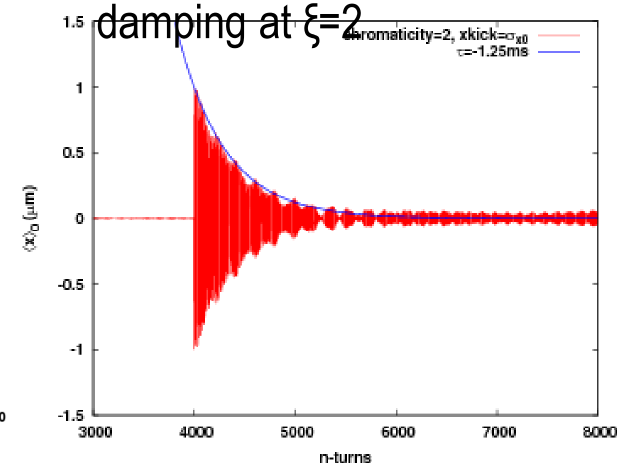


τ_{gr} vs. ΔΩ at $\xi = 0$



$\Delta\Omega, kHz$

Slow head-tail effect: damping at ξ=2

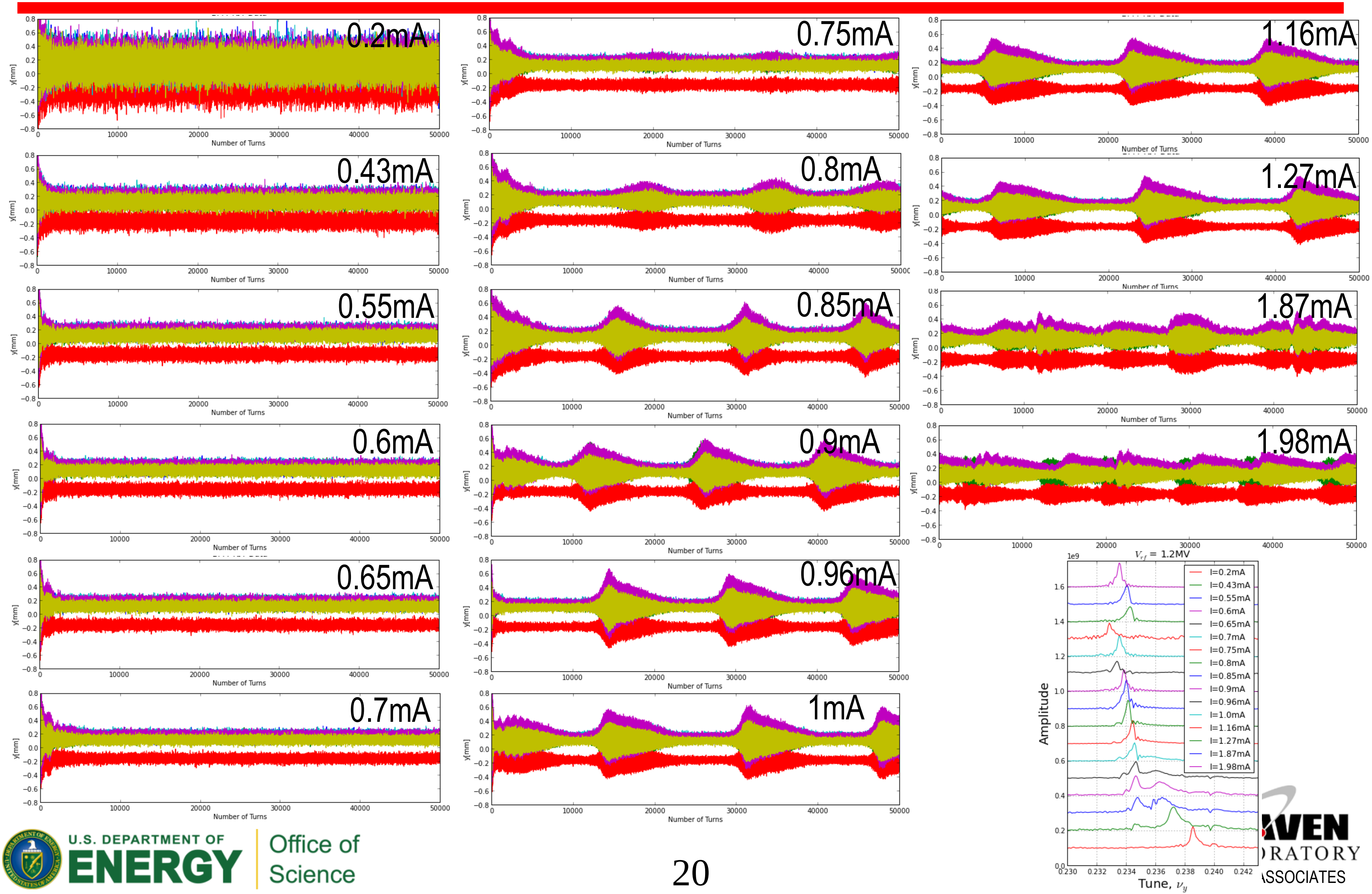


Self consistent simulations of head-tail effect + coupled-bunch interaction with the OASIS code

Working Points (ξ,ΔΩ)

M=132, N=3.1x10^9, R_{BB} =1MΩ/m: (1,60KHz), (2,40KHz)
M=132, N=3.1x10^9, R_{BB}=0.5MΩ/m : (1,110KHz), (2,70KHz)
M=66, N=6.2x10^9, R_{BB}=0.5MΩ/m : (1,60KHz), (2,40KHz)

Phase 2, Vertical TbT Data (+2/+2, V_{RF}=1.2MV)



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