Upgrade of the ATF Damping Ring BPMs & Beam Tests

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for the ATF DR BPM Upgrade Collaboration

ATF DR BPM Collaboration

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- Peter Prieto
- Dennis Nicklaus
- Ron Rechenmacher
- Duane Voy
- Manfred Wendt

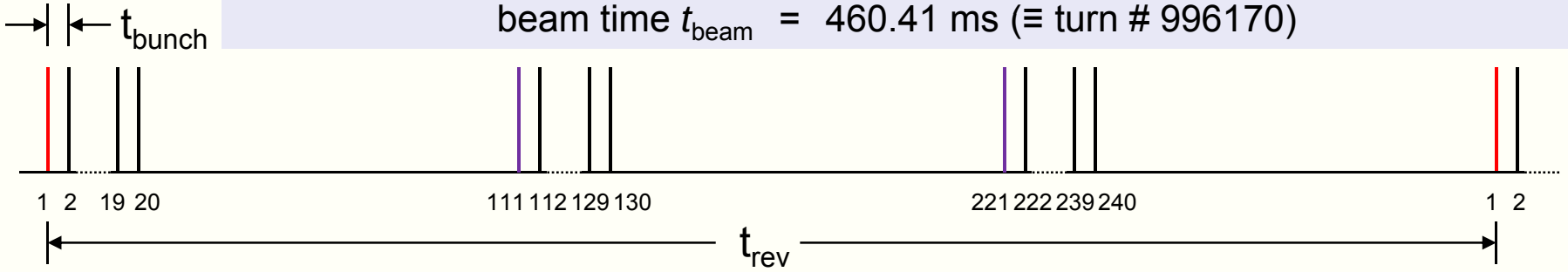
…and many others!

Motivation

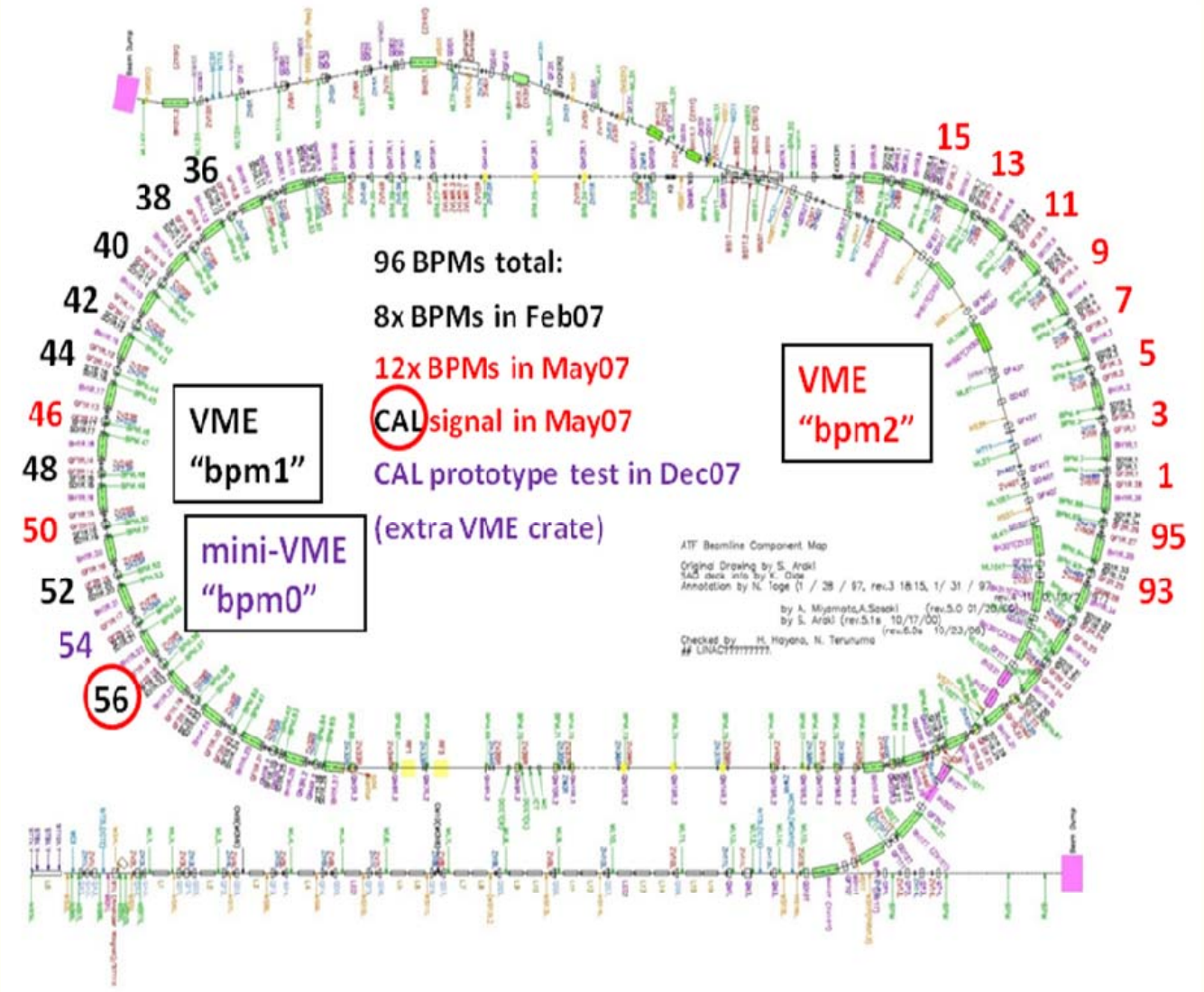
- ILC damping ring R&D at KEK's Accelerator Test Facility (ATF):
  - Investigation of the beam damping process (damping wiggler, minimization of the damping time, etc.)
  - Goal: generation and extraction of a low emittance beam ($\varepsilon_{vert} < 2$ pm) at the nominal ILC bunch charge
- A major tool for low emittance corrections: a high resolution BPM system
  - Optimization of the closed-orbit, beam-based alignment (BBA) studies to investigate BPM offsets and calibration.
  - Correction of non-linear field effects, i.e. coupling, chromaticity,…
  - Fast global orbit feedback(?)
  - Necessary: a state-or-the-art BPM system, utilizing
    - a broadband turn-by-turn mode (< 10 μm resolution)
    - a narrowband mode with high resolution (~ 100 nm range)

The ATF Damping Ring

Machine and Beam Parameters		
beam energy E	=	1.28 GeV
beam intensity, single bunch	≈	~1.6 nC ≡ 10^{10} e^- (≡ I_{bunch} ≈ 3.46 mA)
beam intensity, multibunch (20)	≈	~22.4 nC ≡ 20 x0.7 10^{10} e^- (≡ I_{beam} ≈ 48.5 mA)
accelerating frequency f_{RF}	=	714 MHz
revolution frequency f_{rev}	=	f_{RF} / 330 = 2.1636 MHz (≡ t_{rev} = 462.18 ns)
bunch spacing t_{bunch}	=	t_{RF} / 2 = 2.8011 ns
batch spacing t_{batch}	=	t_{rev} / 3 = 154.06 ns
horizontal betatron tune	≈	15.204 (≡ f_h ≈ 441 kHz)
vertical betatron tune	≈	8.462 (≡ f_v ≈ 1000 kHz)
synchrotron tune	≈	0.0045 (≡ f_s ≈ 9.7 kHz)
repetition frequency f_{rep}	=	1.56 Hz (≡ t_{rep} = 640 ms)
beam time t_{beam}	=	460.41 ms (≡ turn # 996170)

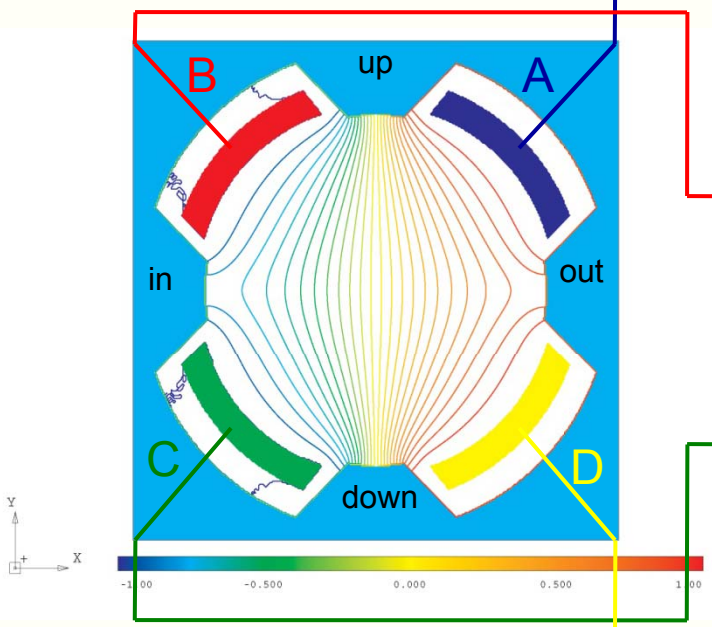


The ATF Damping Ring



BPM Hardware Overview

Beam Position Signal Processing



Down Mix A
BPF LPF

Down Mix B
BPF LPF

Down Mix C
BPF LPF

Down Mix D
BPF LPF

"Echotek" digital signal processing:

$$\phi_H = \frac{(A+D)-(B+C)}{A+B+C+D}$$

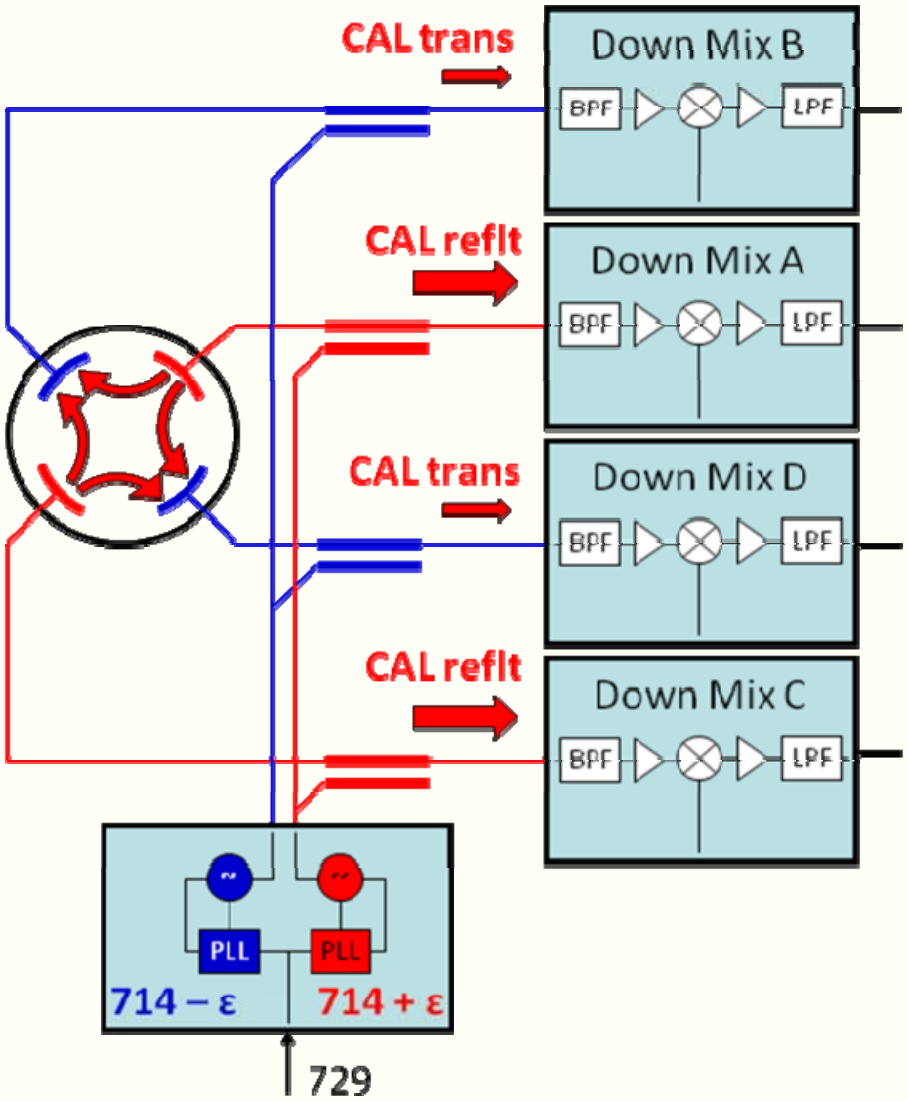
$$\phi_V = \frac{(A+B)-(C+D)}{A+B+C+D}$$

1D polynomial fit:

$$Pos[mm] = 9.35\phi + 1.00\phi^3 + 7.79\phi^5$$

0.1 dB gain error ≡
27 μm offset error !

Calibration Schema



- 2 calibration tones:
  - 714 + ε MHz
  - 714 – ε MHz
  - In passband of the downconverter
  - Coupled through the button BPM
  - Alternative: Reflected CAL signal
- On-line calibration
  - In presents of beam signals
  - Available only in narrowband mode
  - Using separate *Graychip* channels

Calibration Details

- **Calibration tone frequencies:**
  - f_{CALx} = 713.6 MHz
  - f_{CALy} = 714.4 MHz
- **Calibration procedure:**
  - **Correction values:**

$$A_{Corr} = \frac{A_{CAL} + B_{CAL} + C_{CAL} + D_{CAL}}{4A_{CAL}} \qquad B_{Corr} = \frac{A_{CAL} + B_{CAL} + C_{CAL} + D_{CAL}}{4B_{CAL}}$$

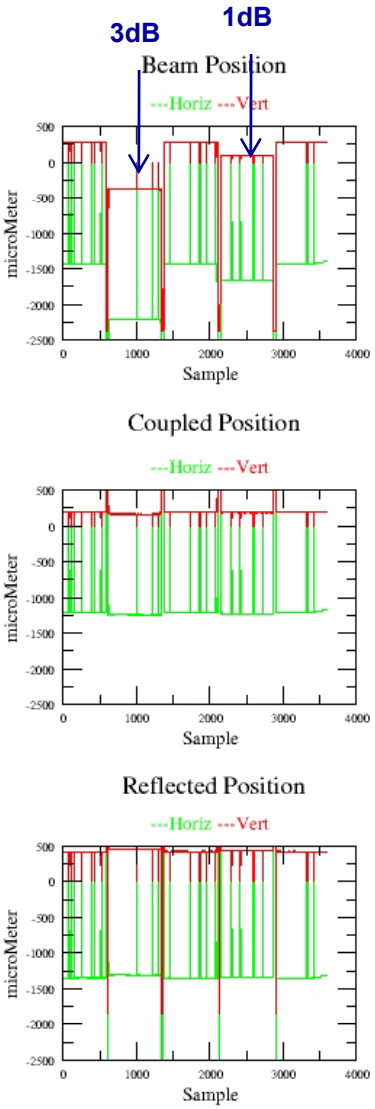
$$C_{Corr} = \frac{A_{CAL} + B_{CAL} + C_{CAL} + D_{CAL}}{4C_{CAL}} \qquad D_{Corr} = \frac{A_{CAL} + B_{CAL} + C_{CAL} + D_{CAL}}{4D_{CAL}}$$

  - **Corrected beam positions:**

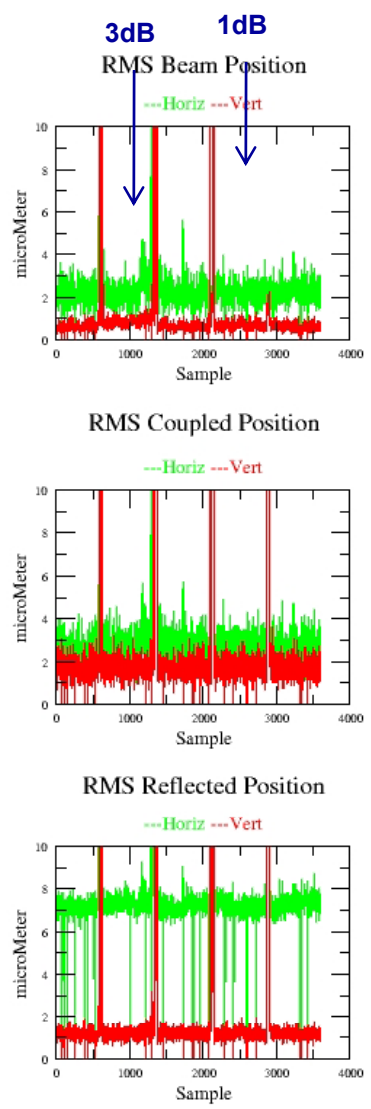
$$\phi_{Hcorr} = \frac{(A\,A_{Corr} + D\,D_{Corr}) - (B\,B_{Corr} + C\,C_{Corr})}{A\,A_{Corr} + B\,B_{Corr} + C\,C_{Corr} + D\,D_{Corr}}$$

$$\phi_{Vcorr} = \frac{(A\,A_{Corr} + B\,B_{Corr}) - (C\,C_{Corr} + C\,C_{Corr})}{A\,A_{Corr} + B\,B_{Corr} + C\,C_{Corr} + D\,D_{Corr}}$$

CAL System: Dec07 Test

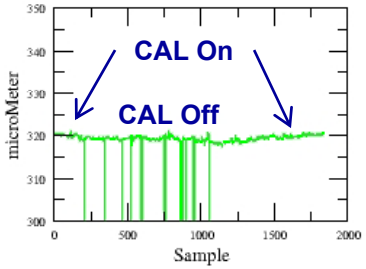


- Calibration on, datalogger on
- Comparing uncorrected, corrected (coupled-through), and corrected (reflected)
- Introduce large 3 & 1 dB gain errors.
- Automatic correction compensates the gain error almost completely!!
- Corrected beam position shows a slight increase of the RMS error (to be further studies!).

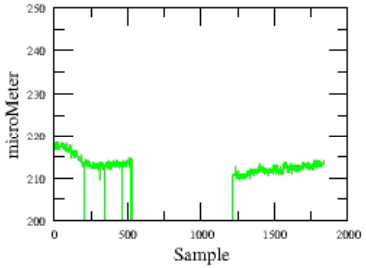


CAL System: Dec07 Test (cont.)

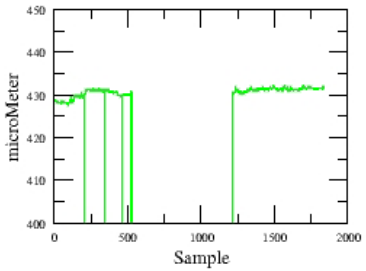
Vert. Beam Position



Vert. Coupled Position

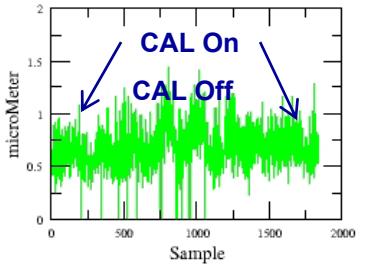


Vert. Reflected Position

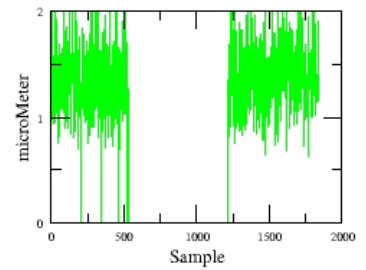


- Calibration On/Off
- No change in vertical beam position observed!
- No influence on the RMS resolution observed!
- Too much beam motion in the horizontal plane (therefore not shown).

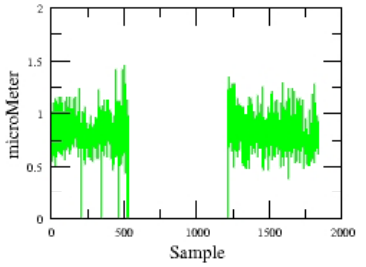
Vert. RMS Beam Position



Vert. RMS Coupled Position

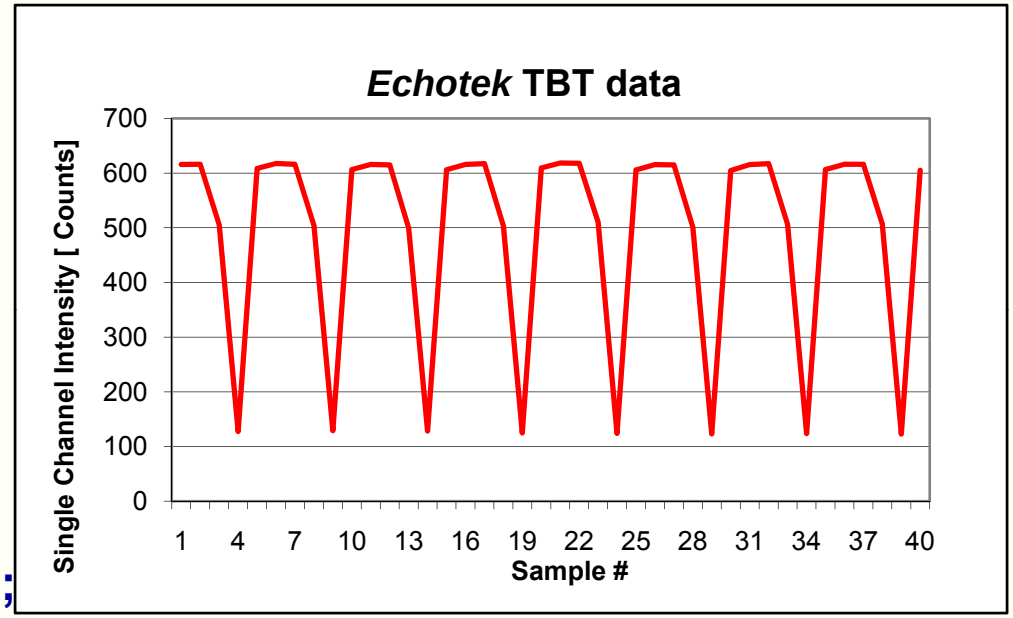


Vert. RMS Reflected Position



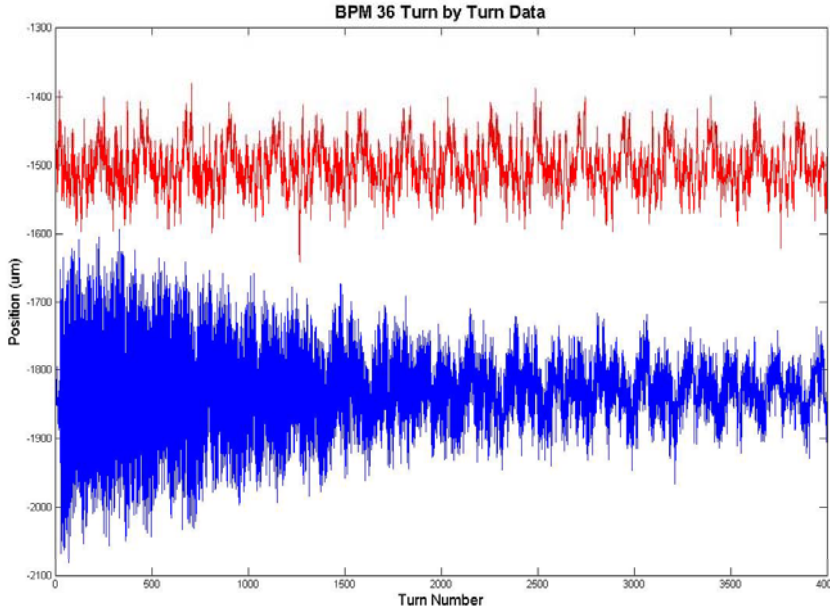
Wideband, TBT Mode Beam Tests

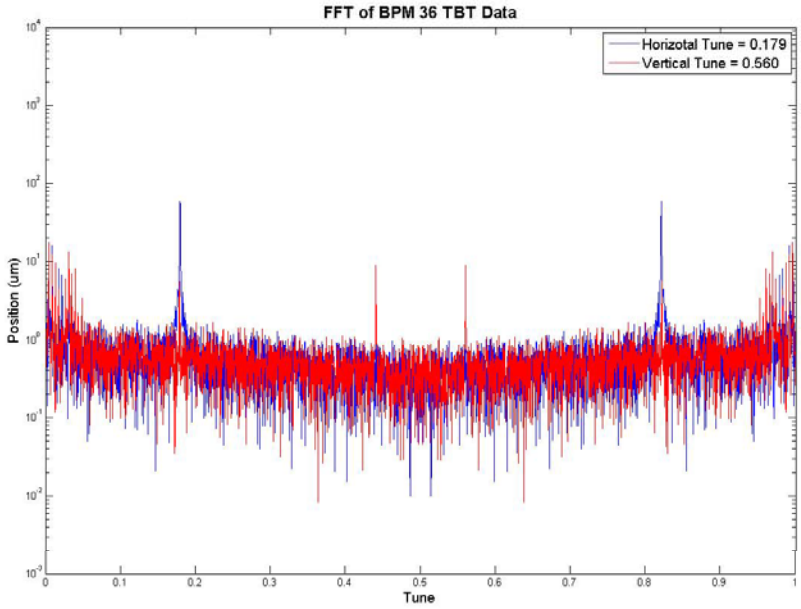
- Several "issues" had to be resolved:
  - CIC & FIR digital filter impulse responses to resolve true turn-by-turn data (no "smearing")
  - Timing issues, e.g. channel-to-channel, as well as between BPMs and "houses" (VME crates); and of course the usual "seam" problem.



- In particular for the kicked beam TBT response tests:
  - Vertical beta at pinger is 0.5 m (12 times smaller than the horizontal one): we had to resort to injection oscillations -> lower resolution.

Kicked Beam Tests May 2007





- Turn-by-Turn data BPM #36 (pinger: On)
- Identifying hor. and vert. tune lines (387 kHz, 1.212 MHz).
- Observed short time, broadband TBT resolution: few μm!
- Observation of "fake" harmonics at n x 10 kHz (not f_s), due to power supply EMI in the analog downconverter unit!

TBT Fourier Analysis

- **TBT data at the *j*th BPM following a single kick in the *z*-plane (*z* ≡ *x*, *y*):**

$$z_n^j = \frac{1}{2}\sqrt{\beta_z^j}\, e^{i\Phi_z^j}\, A_z\, e^{iQ_z(\theta_j + 2\pi n)} + c.c.$$

  - **with**

$n \equiv$ turn number , $\quad A_z = |A_z| e^{i\delta_z} \equiv$ constant of motion

$$\Phi_z \equiv \mu_z - Q_z\theta \quad \text{(periodic phase function)}$$

- **Twiss functions:**

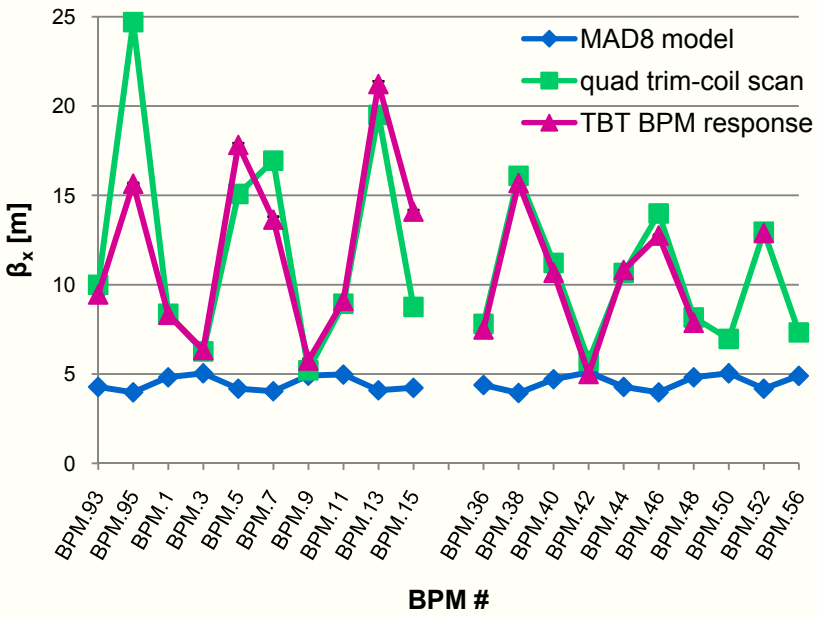
$$\beta_z^j = |Z_j(Q_z)|^2 / A_z^2 \qquad \mu_z^j = \arg(Z_j) - \delta_z$$

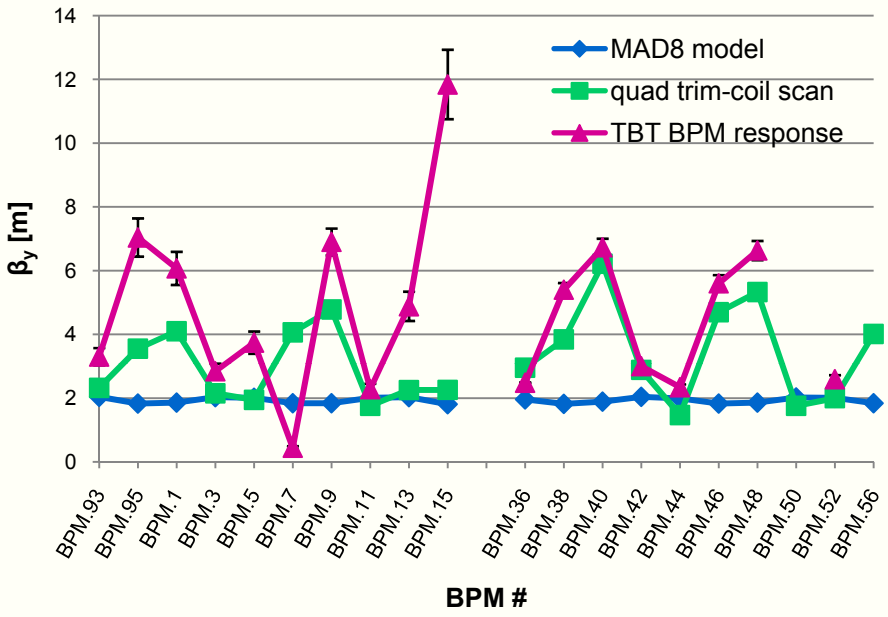
$Z_j(Q_z) \equiv$ *Fourier* component of z_j

- **Amplitude fit:**

$$|A_z|^2 = \frac{\sum_j 1/\beta_z^{0\,j}}{\sum_j 1/|Z_j(Q_z)|^2}$$

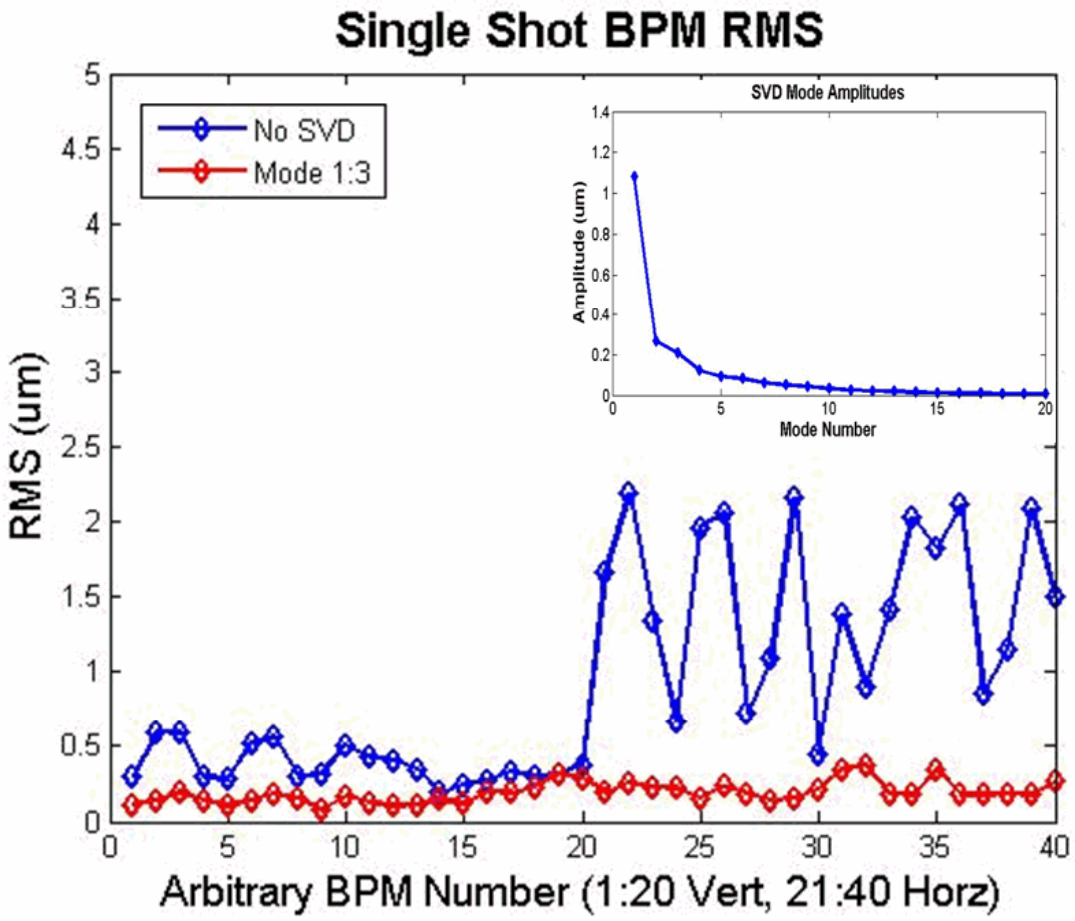
Comparison: Measurements vs. Model





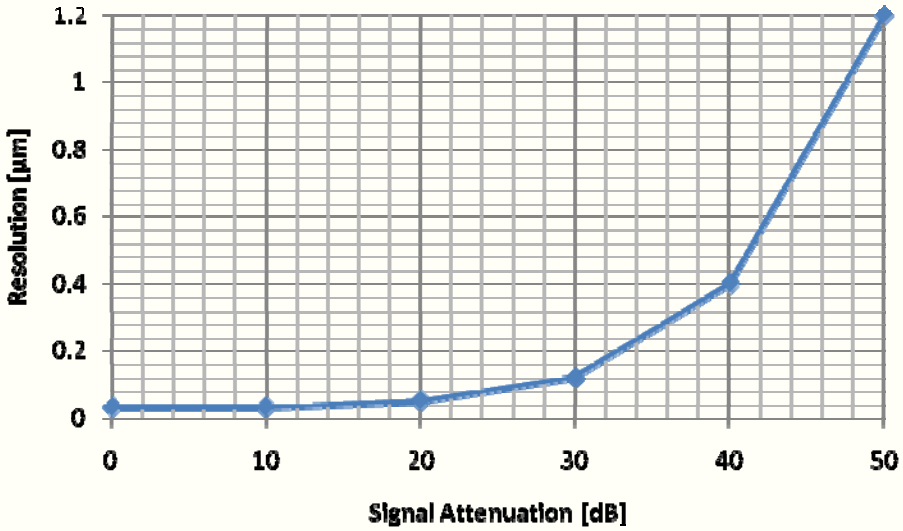
- MAD8 model (M. Woodley, marginal differences wrt. Kuroda SAD model).
- Nearby quadrupole trim coil scan (May 2008).
- TBT Fourier analysis, amplitude by fit to beta measured through trim coil scan (April 2008).

Narrowband Mode Resolution



- Triggered at turn #500,000
- ~200 ms position data per shot (1280 narrowband mode BPM measurements).
- 126 tap box car filter to reject 50 Hz:
  - ~ 800 nm resolution
- SVD analysis, removing modes with hor./ vert. correlation:
  - ~200 nm resolution

NB Mode Resolution Limit



Theoretical:

- ADC SNR: 75 dB
- Process gain: 40.4 dB
- NF 1st gain stage: ~ 1 dB
- CAL tone level: -10 dBm
- Splitter attenuation: 6 dB
- Effective gain: ~ 100 dB
- BPM sensitivity: 240 µm/dB
- Calculated equivalent resolution: ~ 20 nm

CAL tone resolution measurement on BPM #56: ~30 nm(!) equiv. resolution (no beam operation at ATF!, magnets off)

Future Steps…!?

- **Need to resolve known issues (cannot resolved remotely!):**
  - Two defect downmix units
  - EMI interference into downmix electronics
- **Need a revised plan for BPM upgrade:**
  - Total number of BPMs
  - Verify current upgrade concept
  - Detailed cost analysis
- **Need funds(!):**
  - Travel for hardware repairs and improvements, e.g. synchronize VME crates, increase clock rate (32 -> 40 samples/turn), etc.
  - New BPM installations
- **Most soft-/firmware activities & beam studies: Remote operation!**