RHIC BPMs: Status and Experiments

Todd Satogata

Rob Michnoff, Tom Russo, Craig Dawson, Phil Cerniglia, Chris Degen, Justin Gullotta, Tony Curcio, Bob Sikora, Siegfried Naase, Ron Schroeder, Paul Ziminski, John Carlson, Steve Jao, operators…

Jen Niedziela, Christoph Montag, Yun Luo, Peter Cameron…

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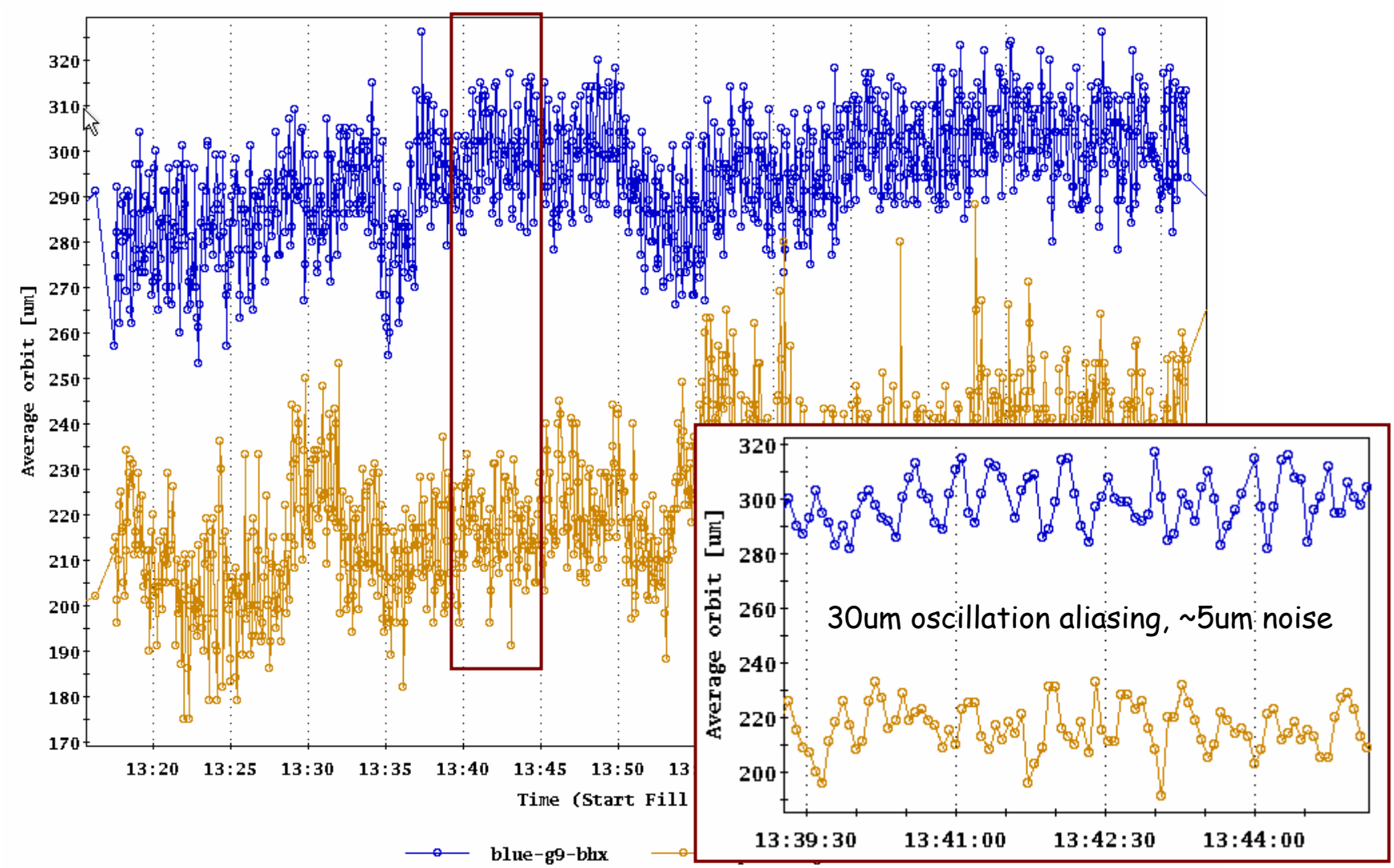
- Functionality summary
- Upgrade status and summary
- Accelerator physics experiments

RHIC BPM Functionality

- General
  - Position resolution is 1um, 16 bit (slow) serial DAC
  - Bunch selectable on per-plane basis
  - Acquiring every turn; not always writing to buffers
  - Two gain stages (x1/x10): x1 good for ~2-30e10 p
  - Self-calibrate with on-board pulser
  - Peak detect/sample and hold "gated" trigger mode, and direct digitizer sample "dead-reckoned" mode
  - All measurements report corrected digitizer counts
- Turn by Turn (<50 um RMS reproducibility)
  - Reports 1024 consecutive turns on beam sync event
  - Eight planes modified to report over ten million turns
- Average Orbit (<5 um RMS reproducibility)
  - Reports average/rms of 10,000 turns on beam sync event

Typical Average Orbit Data (at store)



BPM Hardware Upgrades

- Large-scale effort to modify hardware for all BPMs
  - 724 planes removed/modified/installed, 35-40 spares
  - Every plane bench tested and bench calibrated
  - Tens of man-months of effort, including operations
    - ⇨ Completed Oct 30, now testing (nearly) end to end integrity

- Hardware modifications include
  - Removal of all six relays in signal path
  - Installation of signal combiner board for on-board pulser
  - Installation of x1/x10 gain boards
  - Resistor gain change to avoid trigger jitter (injection TBT)
  - Optoisolator and other failed component repairs as necessary
  - Development of bench testing procedure, large assembly line

BPM Software Upgrades

- DSP code changes
  - Turn offset problem fixed (injection)
  - Internal calibration (in progress)
- Altera code bug fixes
  - Fixes timing delay channel problems, hair race conditions
- ADO
  - Better failure detection, alarming on failure
- System-wide
  - Start with gated triggering before RF capture in setup
  - Use fixed timing after RF capture in setup
    - ⇨ Expect to take 1-2h to scan and set up timing
    - ⇨ Improve robustness of all BPMs, particularly DX BPMs
    - ⇨ Wish list: BPM timing scan, peak search in DSP

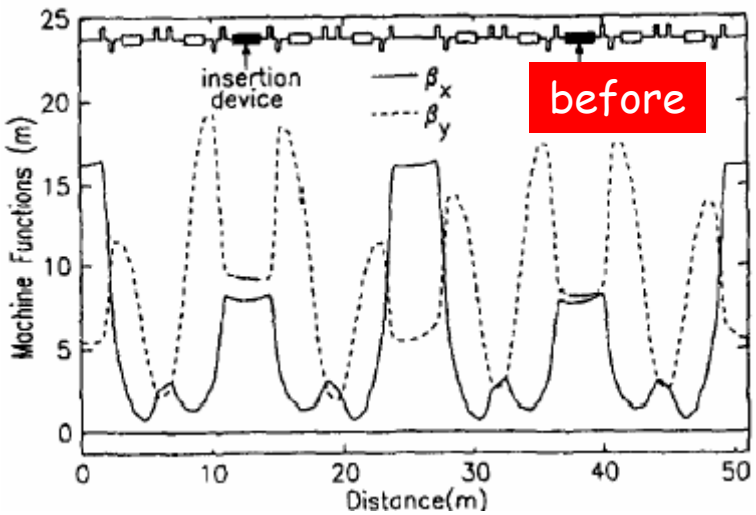
Response Matrix Background

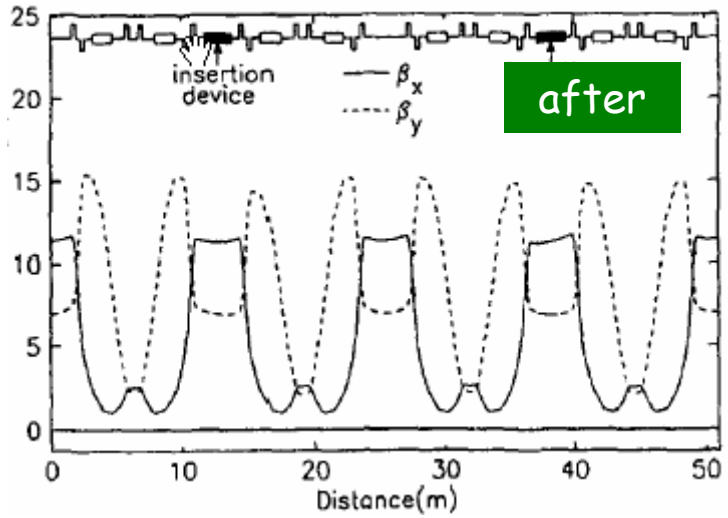
- Orbit response matrix (with coupling/nonlinear feeddown):

$$\begin{pmatrix} \vec{x} \\ \vec{y} \end{pmatrix} = R \begin{pmatrix} \vec{\theta}_x \\ \vec{\theta}_y \end{pmatrix}$$

  where (θ_x,θ_y) are corrector setting changes and (x,y) are measured difference orbits from these corrector settings.
- Compare model and measured R "response matrices", and iteratively make model changes to converge to agreement.
  - "Model changes" include quad gradients, BPM/corr gains, …
  - Measures gradient errors, BPM/corr gain errors, skew errors, …
- "Understand the linear machine"
  - Improve the operational models (online and offline) of RHIC
  - Expect to use routinely for optics verification in APEX

Orbit Response Matrix: NSLS X-Ray Ring, and RHIC



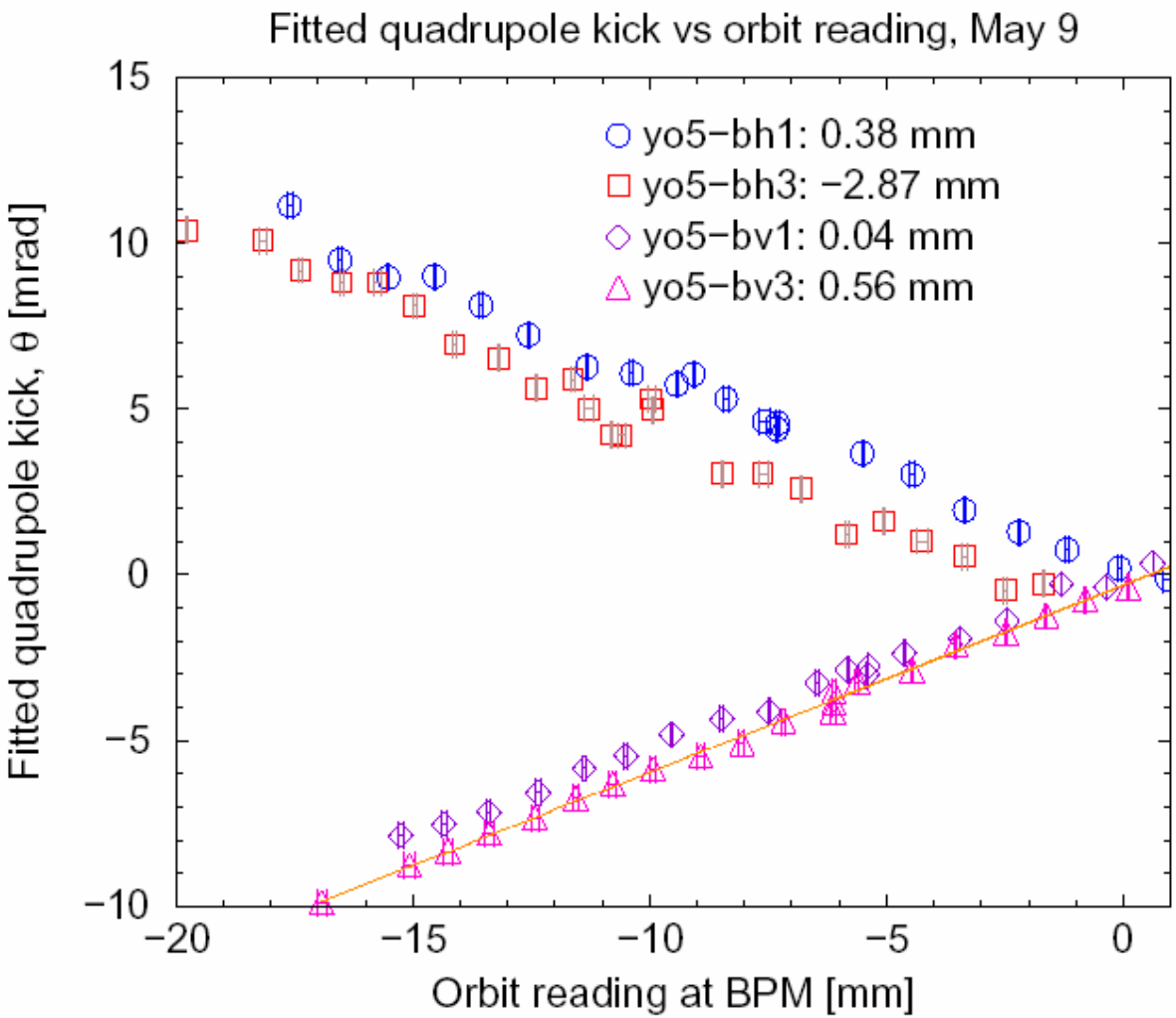


Parameter	RMS variation
Quad gradients	0.04%
Quad rolls	0.4 mrad
BPM gains	0.5%
BPM rolls	0.5 mrad
Steerer gains	0.5%
Steerer rolls	0.8 mrad

Safranek, NIM **388** (1997)

- 334 BPMs, 234 correctors in RHIC
  - All correctors: ~40 minutes
  - 30 correctors: ~5 minutes
- Software from Sajeev, Safranek
  - Will verify BPM gain calibrations

Quadrupole Beam Based Alignment



- Detailed bump scans (25 points) performed to compare against cursory scans with three points
- Agreement is within statistical error bars
- Orbit bumps biased to negative by RHIC injection IR separation bumps

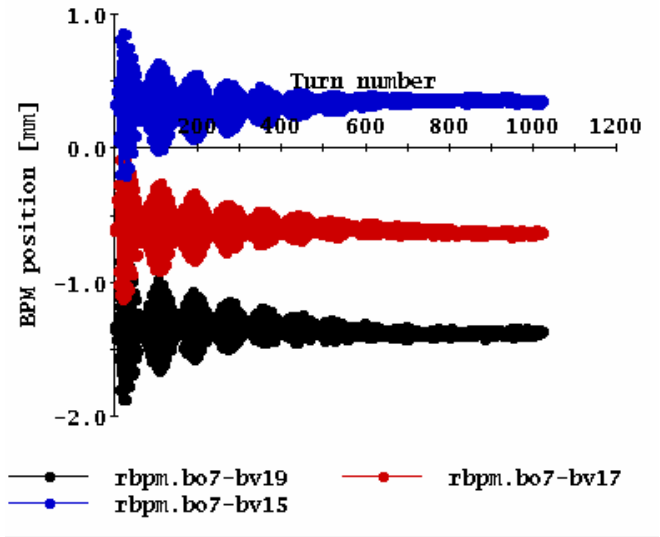
Quadrupole Beam Based Alignment

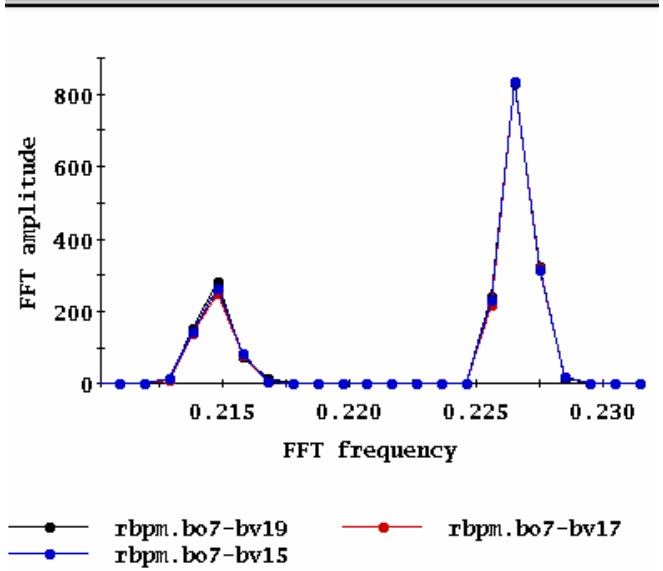
- Modified BPM boards (with relays removed) have o(10) more consistent offsets than boards with original relays
- Accumulated BBA data acquired over 2 months of RHIC operations, includes short- and long-term drift
- No BPMs recalibrated during this study
- T. Satogata, J. Niedziela

Name	Horizontal [mm]	Vertical [mm]
bi5-qf3	-1.07 ± 0.16	-0.24 ± 0.00
bi5-qf1	-1.78 ± 0.34	0.08 ± 0.13
bo6-qd1	0.28 ± 0.06	-1.46 ± 0.62
bo6-qd3	-0.33 ± 0.19	-2.59 ± 0.23
bo11-qd1	-0.39 ± 1.62	1.31 ± 1.10
bi12-qf1	-0.87 ± 1.59	2.84 ± 2.85
yo5-qd3	-2.87 ± 0.15	0.56 ± 0.25
yo5-qd1	-0.38 ± 0.22	0.04 ± 0.14
yi6-qf1	-0.56 ± 0.47	-0.03 ± 0.27
yi6-qf3	-1.41 ± 0.40	-0.16 ± 0.18
yi11-qf1	-8.31 ± 1.32	-0.48 ± 0.26
yo12-qd1	-0.38 ± 1.85	1.88 ± 1.50

Red BPM names have unmodified electronics boards

Kicked Ramp TBT: Coupling Studies

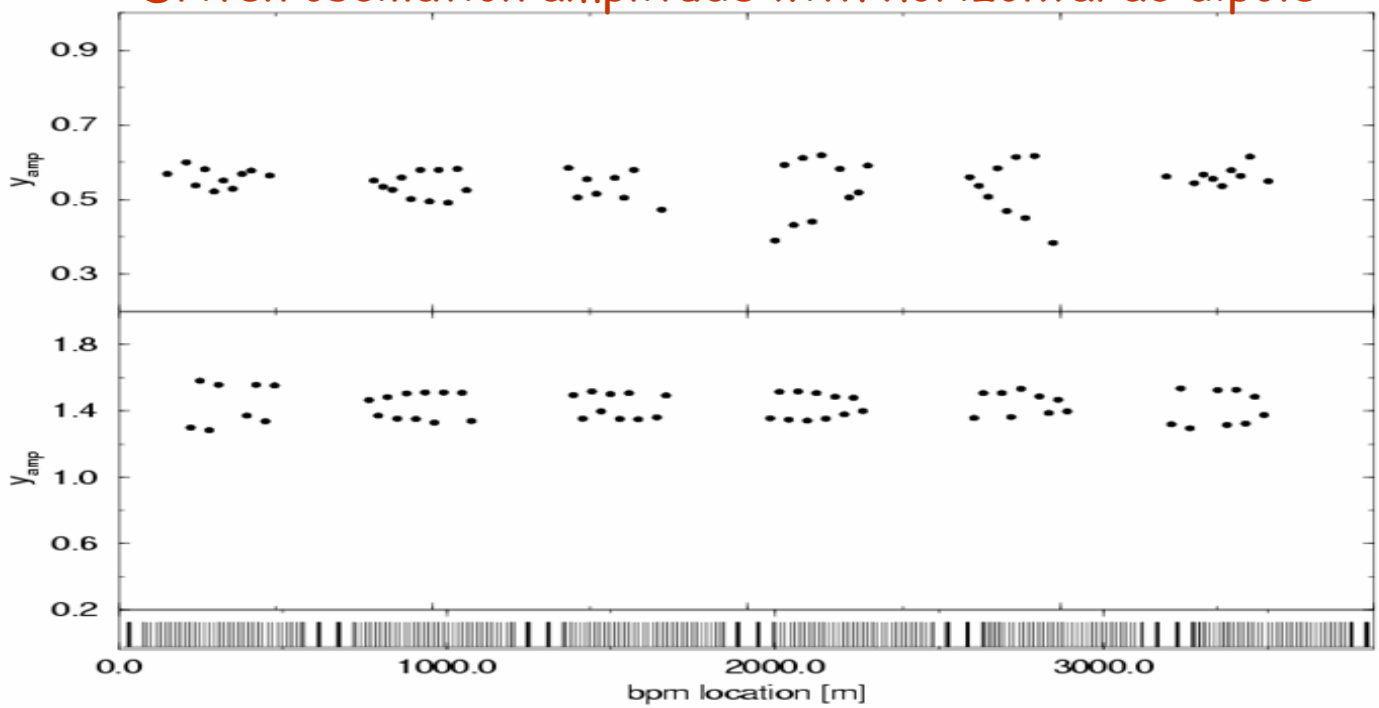




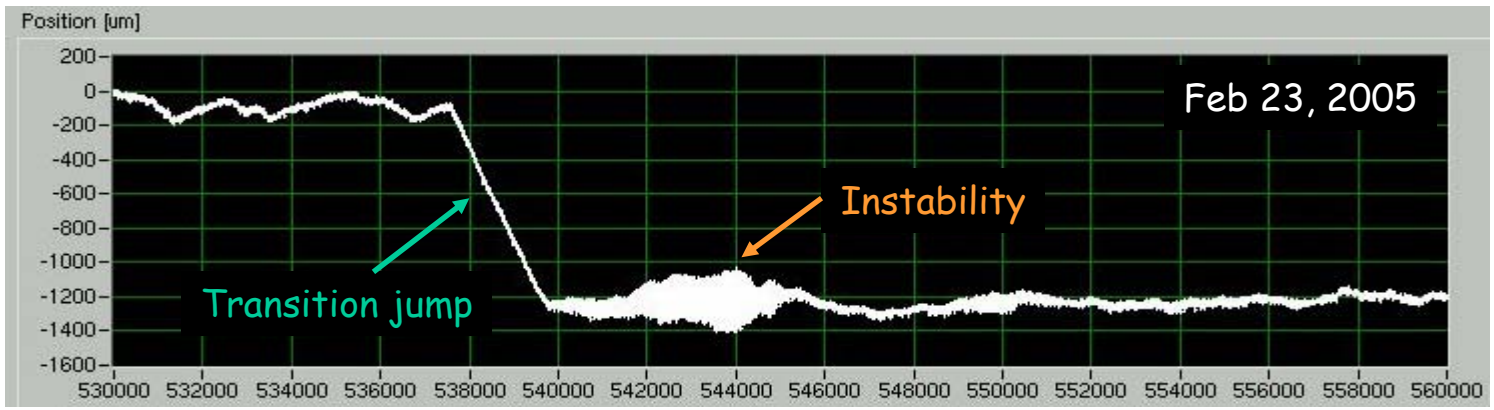
- Kicked TBT data routinely taken during acceleration ramp
  - 1-2mm excitation from tunemeter
  - Optics, decoherence, decoupling
  - BPM sanity checking
- W. Fischer's N-turn map method
  - Should work with improved machine model, BPMs
- APEX: Y. Luo's eigenmode projection method
  - Requires kicks in both planes
- Reliable BPMs make these routine

- Requires accurate, correlated TBT data from all BPMs
  - Will benefit greatly from system upgrades, stability
- Resonant driving terms, transverse coupling (R. Calaga)
  - Potential for correction of nonlinear lattice

Driven oscillation amplitude with horizontal ac dipole

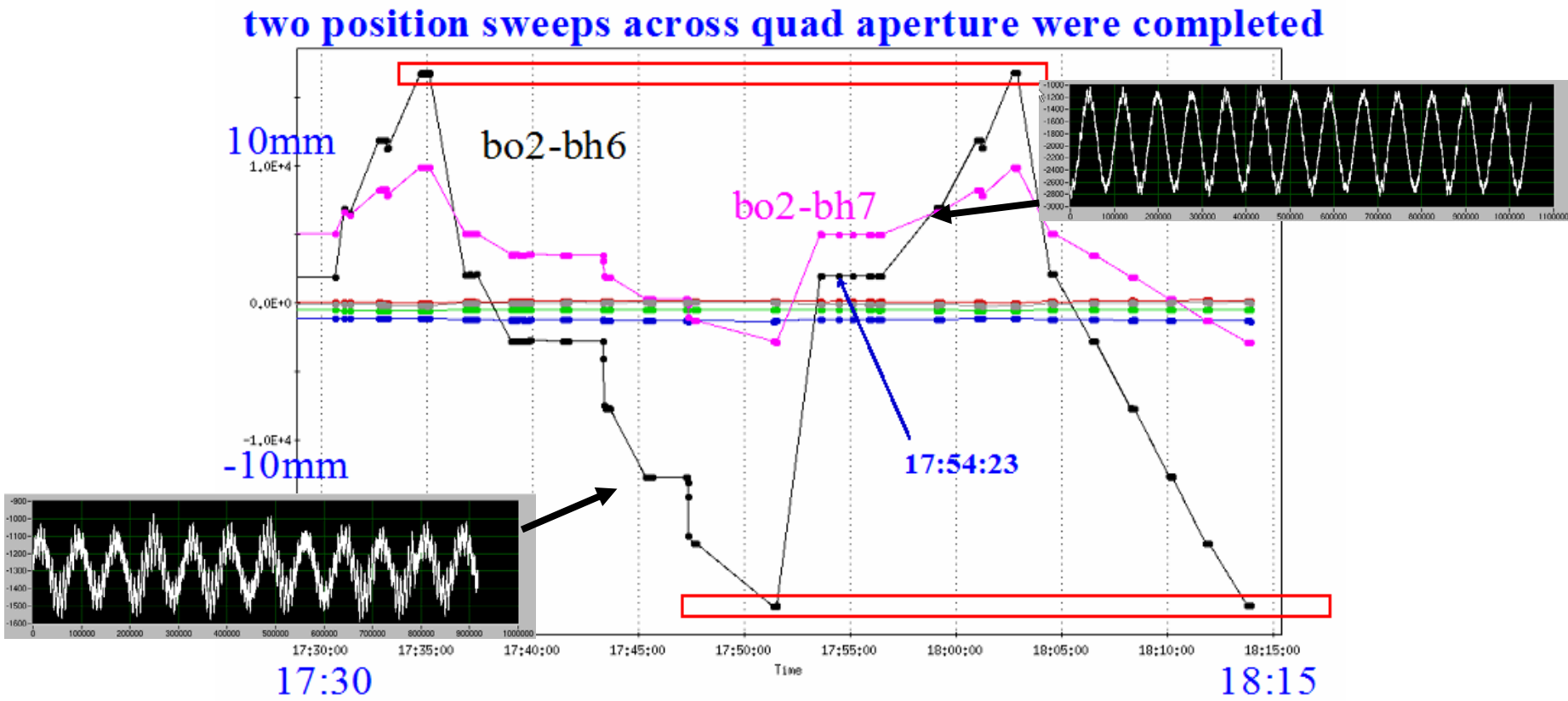


- Two available in each plane, each ring for full phase space
  - bo2-bh8/10, bo2-bv7/9 and yi6-bh7/9, yi6-bv8/10
  - Programmable length, up to ~ 6 minutes of TBT beam
- Transverse echos (W. Fischer)
  - Could not produce very long-lived echos
- Coherent instabilities during ramping (J. Wei et al)
  - Shows coherent transverse instabilities just after transition



- Transverse nonlinear dynamics

Electron cooling BBA ion beam alignment



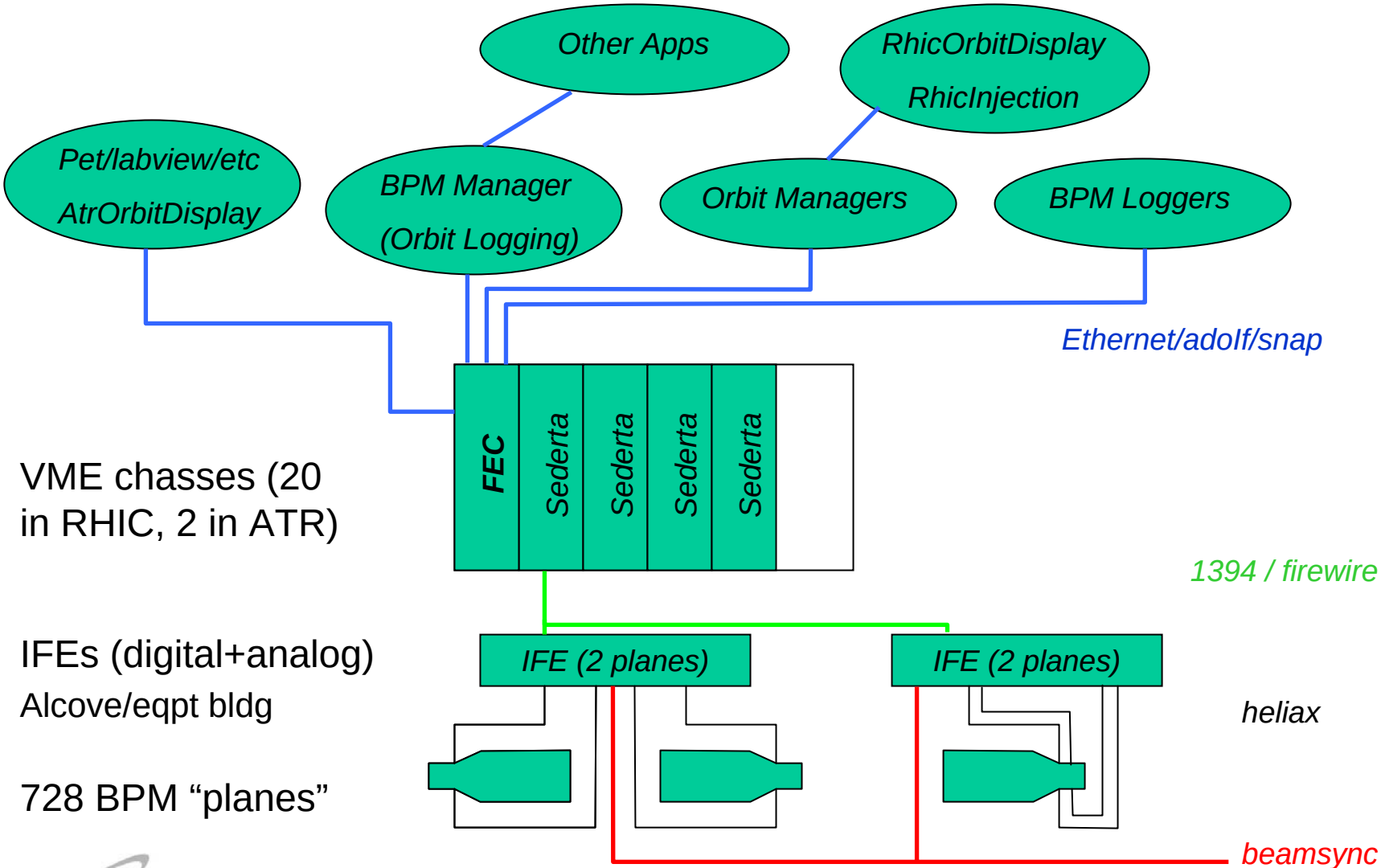
- Move beam position, modulate quadrupole at 1 Hz and measure million-turn BPM response at 1 Hz (P. Cameron et al)

Summary

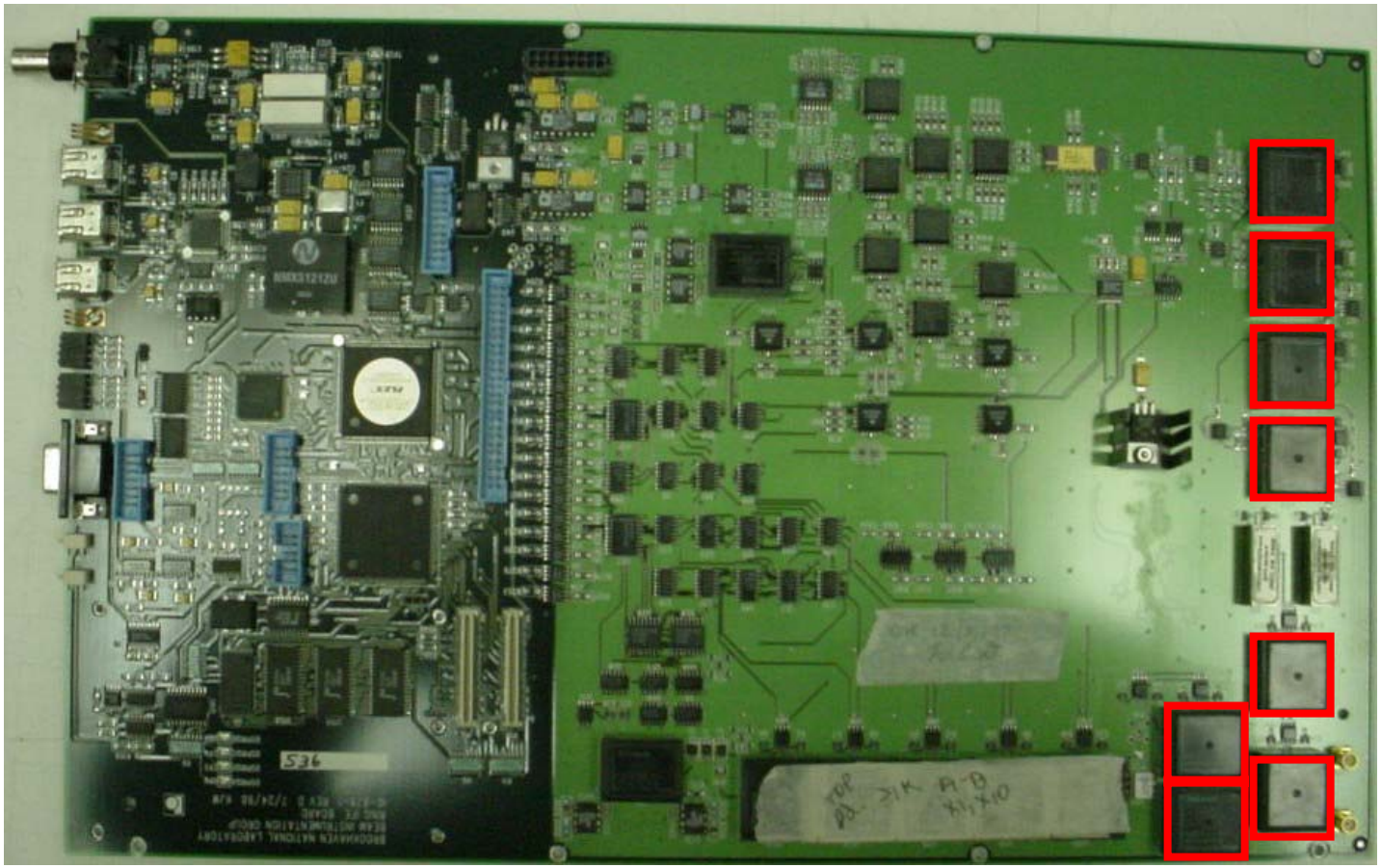
- RHIC BPMs have undergone a large-scale upgrade in FY05
  - All hardware modified, bench tested, bench calibrated
  - Full system dry run test: Thursday Nov 17, 2005
- System functionality expectations:
  - Average orbit reproducibility to 5 um or better
  - TBT orbit reproducibility to 50 um or better
- Many accelerator physics experiments involve the BPMs
  - Orbit response and model improvements
  - Beam-based alignment (IR and gamma-T jump quads)
  - Kicked beam ramp coupling correction
  - AC dipole, optics, and nonlinear driving terms
  - Million-turn BPMs for instabilities, echo, ramp TBT

Spare Slides

BPM System Block Diagram



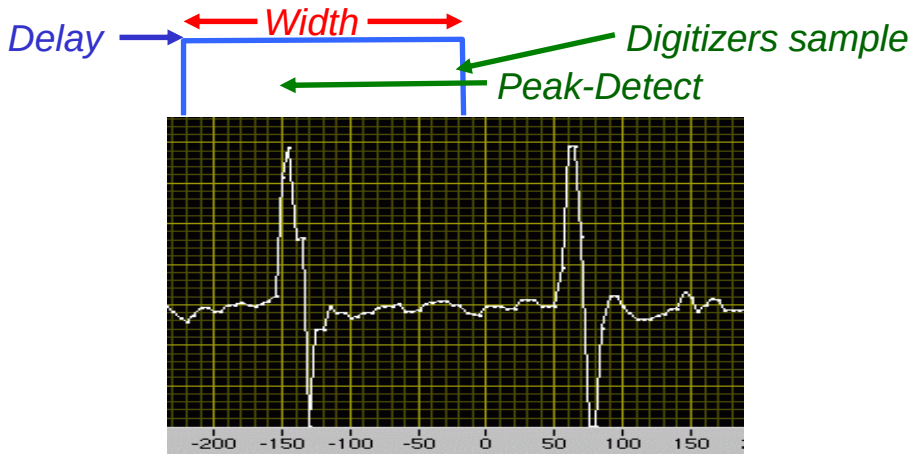
BPM Hardware Board Layout, Relays



- 6 gold-plated relays in signal path
  - Used for gain, not cycled enough, organic membranes formed

Gated and Fixed BPM Timing

- Gated BPM timing
  - Delay and width settings
  - Self-triggers on peak detect
  - Can trigger in wrong place
  - Robust to timing jitter



- Fixed (literally) BPM timing
  - Delay setting only
  - Digitizers fire "immediately"
  - No peak detection necessary
  - Very robust if timing is robust