Argonne NATIONAL LABORATORY

Light Source Instrumentation

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U.S. DEPARTMENT OF ENERGY | Office of Science

Outline

- BPM resolution / orbit stability requirements
- APS orbit correction hardware configuration
- Storage ring beam position monitoring technology
- Lattice measurement and correction at the Advanced Photon Source
- Operational resonant cavity beam position monitoring systems

Beam Stability Requirements

		AC rms Motion, 0.01-200 Hz		Long-term drift (One Week)	
		μm rms	μrad rms	μm rms	μrad rms
Horizontal	Present	5.0	0.85	7.0	1.4
	Upgrade	3.0	0.53	5.0	1.0
Vertical	Present	1.6	0.80	5.0	2.5
	Upgrade	0.42	0.22	1.0	0.5

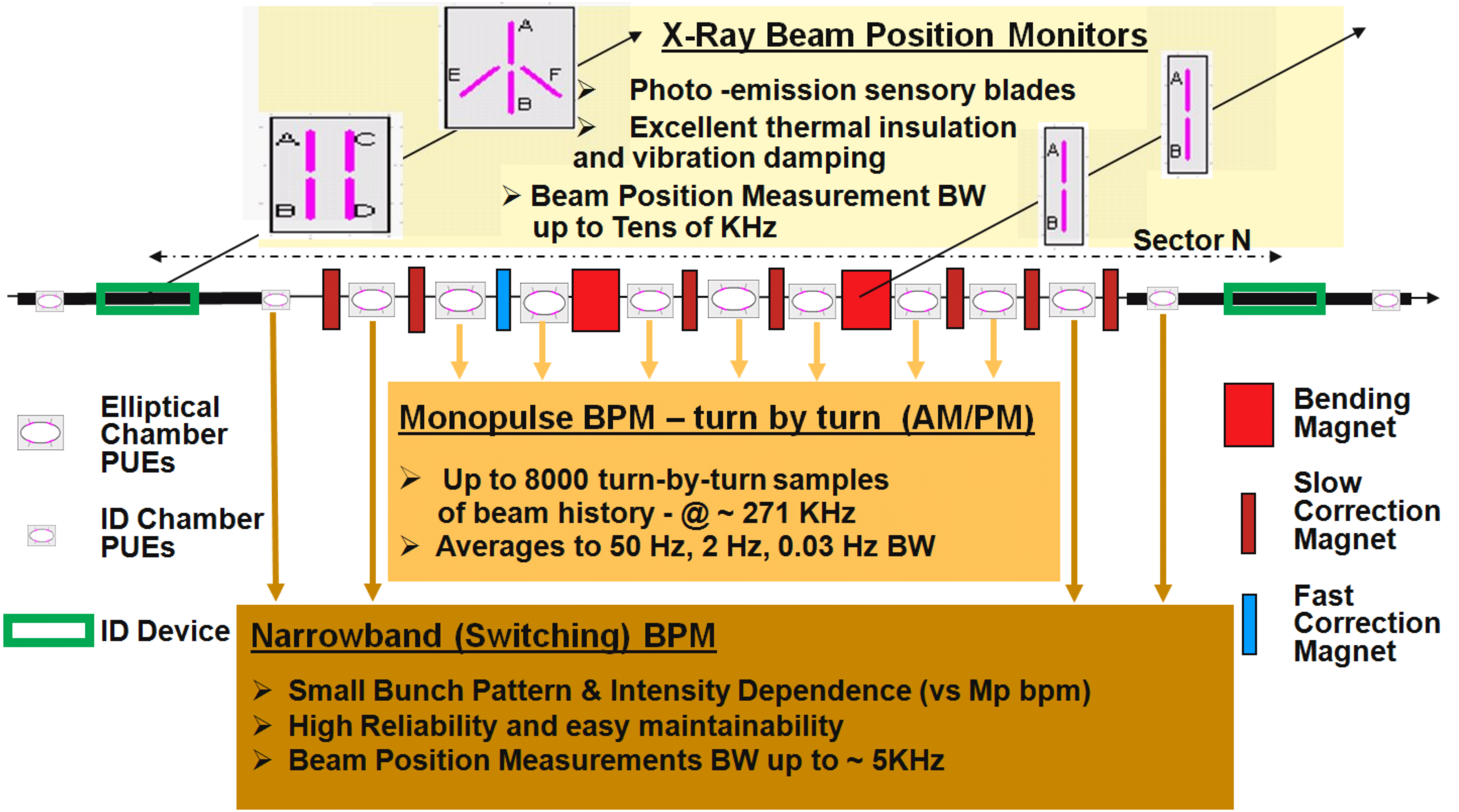
- AC stability derived to be 5% of photon phase space dimensions*
  - Note that best achieved mirror slope error is a few 100 nrad.
- Long-term drift limited by tunnel air and water temperature, and diffusive ground motion (ATL law)**

*J. Carwardine, F. Lenkszus, G. Decker, O. Singh, "Five-Year Plan for APS Beam Stabilization"
http://icmsdocs.aps.anl.gov/docs/groups/aps/documents/report/aps_1192147.pdf

**Bob Lill et al., BIW 2010, Santa Fe, NM
http://accelconf.web.cern.ch/AccelConf/BIW2010/papers/tupsm050.pdf,

V. Shiltsev, "Review of Observations of Ground Diffusion in Space and Time and Fractal Model of Ground motion"
http://prst-ab.aps.org/abstract/PRSTAB/v13/i9/e094801

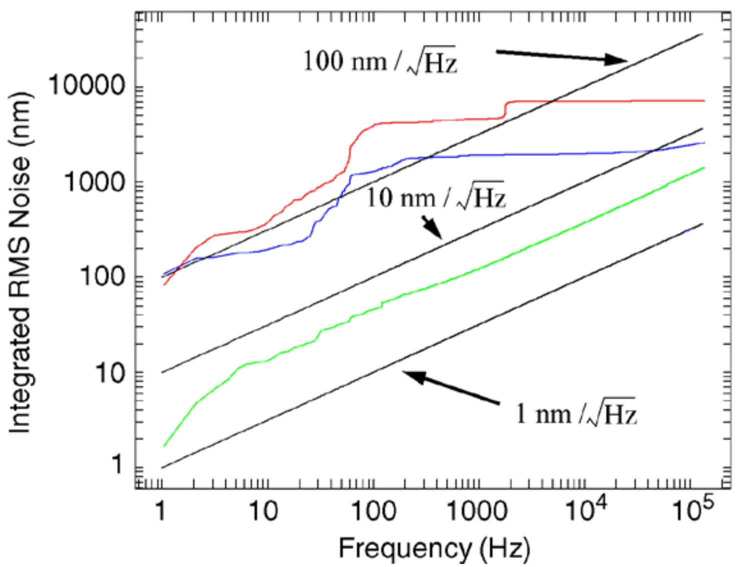
APS Orbit Correction Hardware Configuration (One of Forty Sectors)

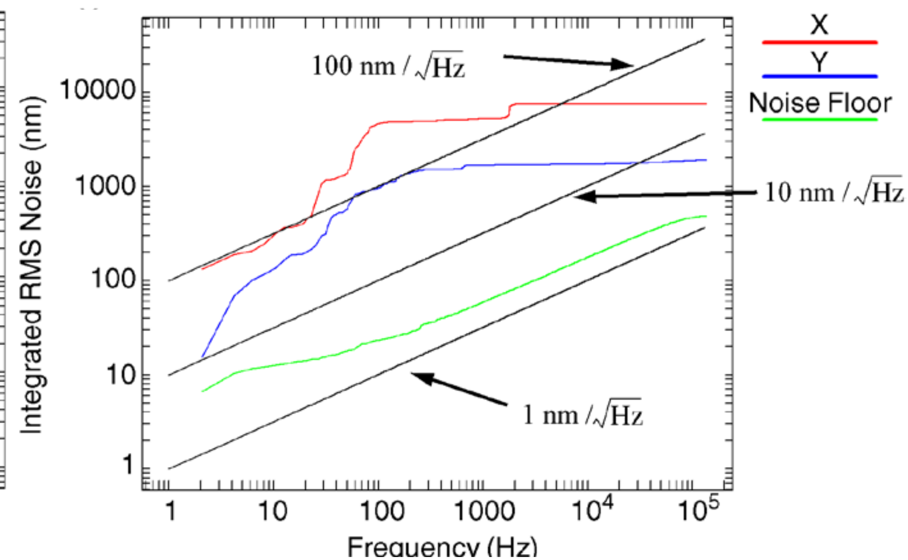


Modern RF BPM Electronics Performance

APS BSP-100 Module

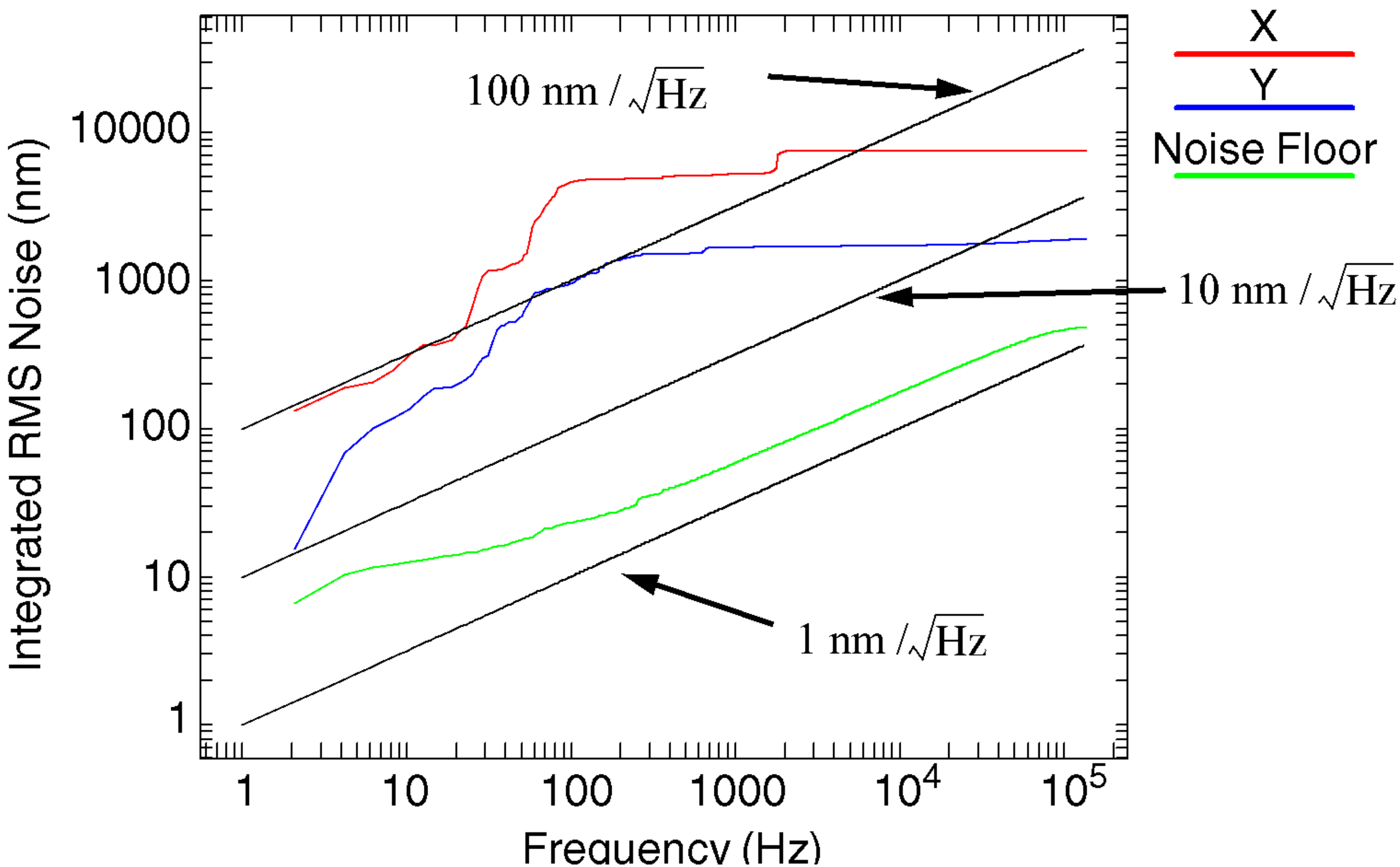
Libera Brilliance@APS





*G. Decker, "APS Beam Stability Studies at the 100-nrad Level", BIW10, http://accelconf.web.cern.ch/AccelConf/BIW2010/papers/tucnb02.pdf

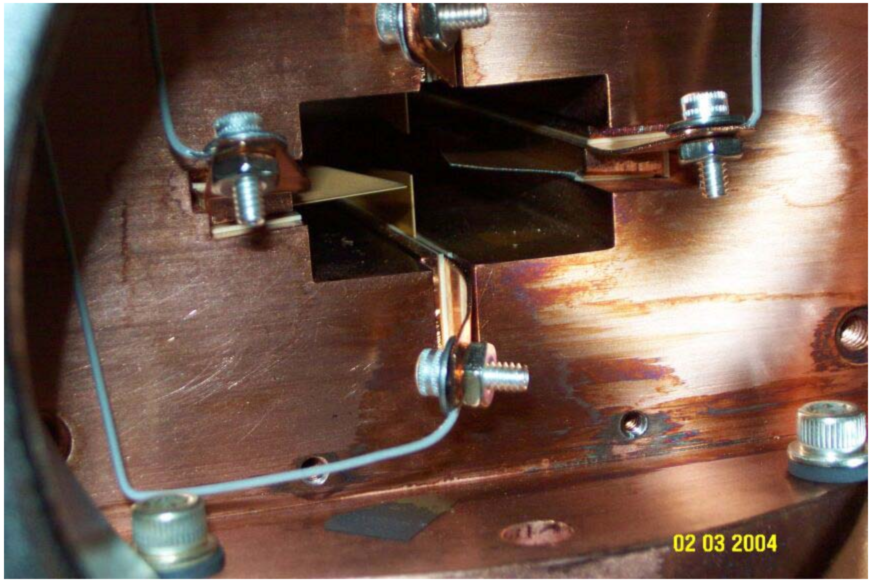
Forward-Integrated Power Spectral Density*



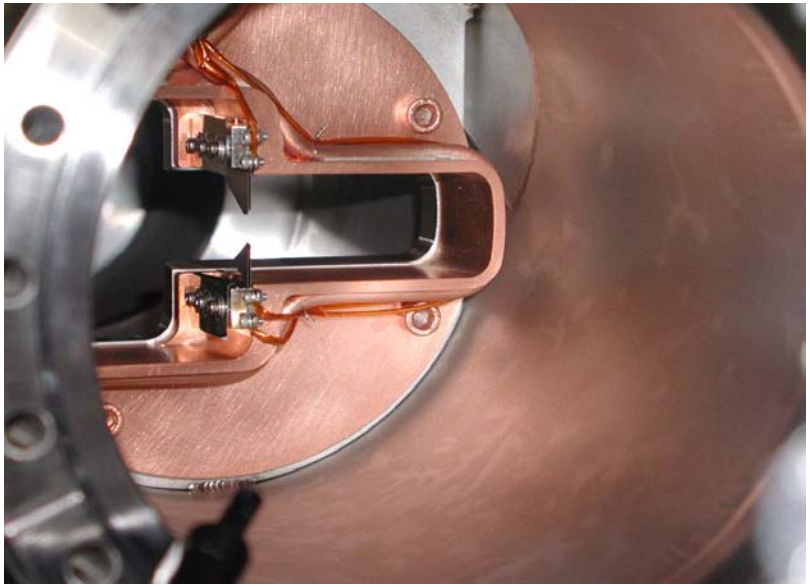
*** Libera Brilliance+ electronics attached to 4-mm diameter capacitive pickup electrodes mounted on small-aperture (8 mm) insertion device vacuum chamber**

Photoemission Blade-Type Photon Beam Position Monitors

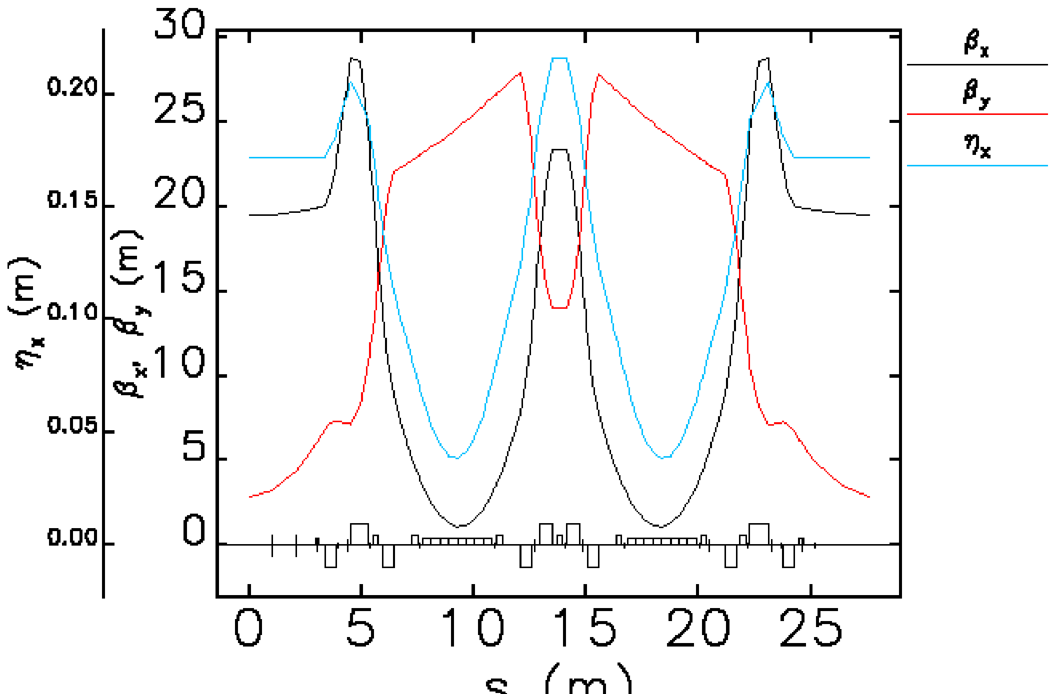
Insertion Device Gold-Plated Diamond Vertical + Horizontal



Bending Magnet Molybdenum Vertical Only



APS Lattice



Twiss parameters for aps

Note: Independent control for every magnet in the machine.

Parameter	Value
Energy	7 Gev
Circumference	1104 meters
Superperiods	40
Q_x, Q_y	36.2, 19.27
Q_s	0.008
F_{rf}	351.927 MHz
X,Y Natural Chromaticities	-90.37, -43.28
RF Voltage	9.5 MV
h_{rf}	$1296 = 2^4 * 3^4$
Natural Emittance	2.5 nm-rad
Effective Emittance@ ID Sources	3.1 nm-rad
Coupling	1%

Response Matrix Least-Squares Fitting

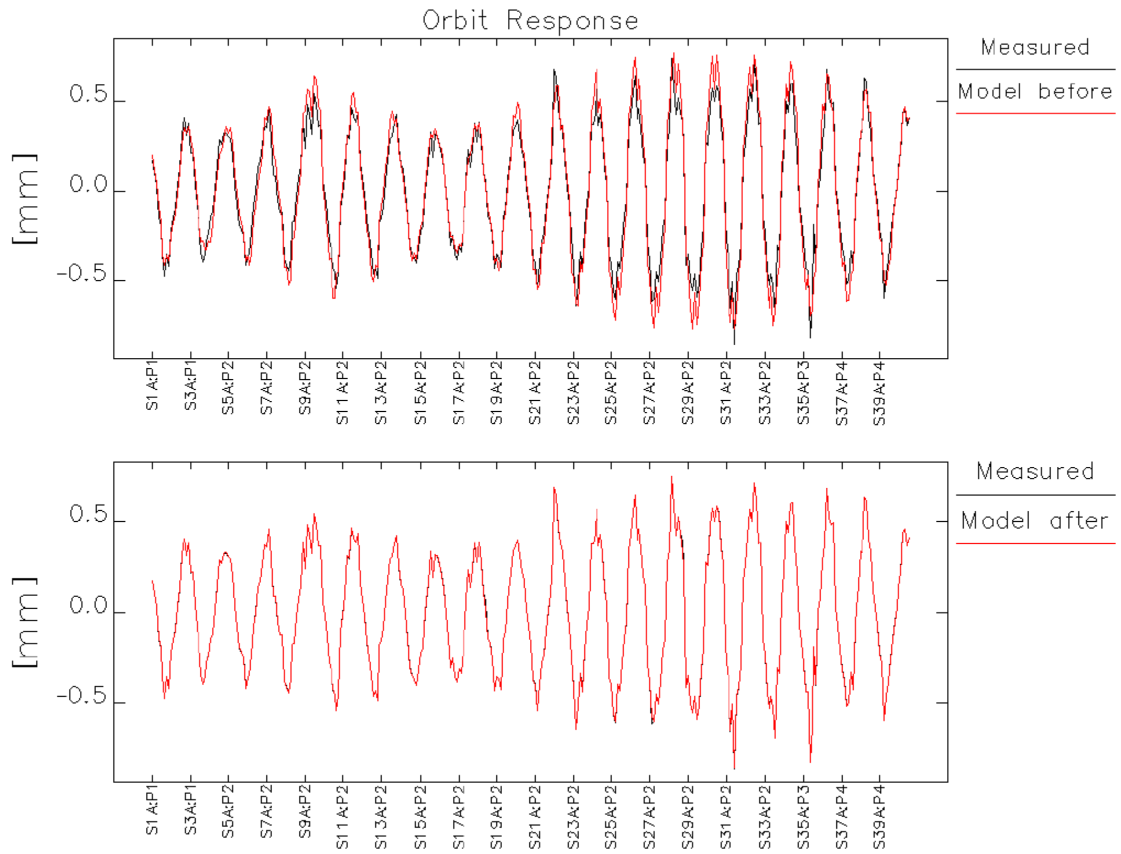


Figure 1. An example of the orbit shift due to a change in a steering magnet (black line is the measurement, red line is the model). Before fitting (top plot), there is significant discrepancy between the model and the measurements. After fitting (bottom plot), the rms difference between the model and the measured orbit is reduced to 1 μm.

*J. Safranek, "Experimental determination of storage ring optics using orbit response measurements", NIM-A **388** (1997) pp. 27-36

Response Matrix Fitting Method – Results*

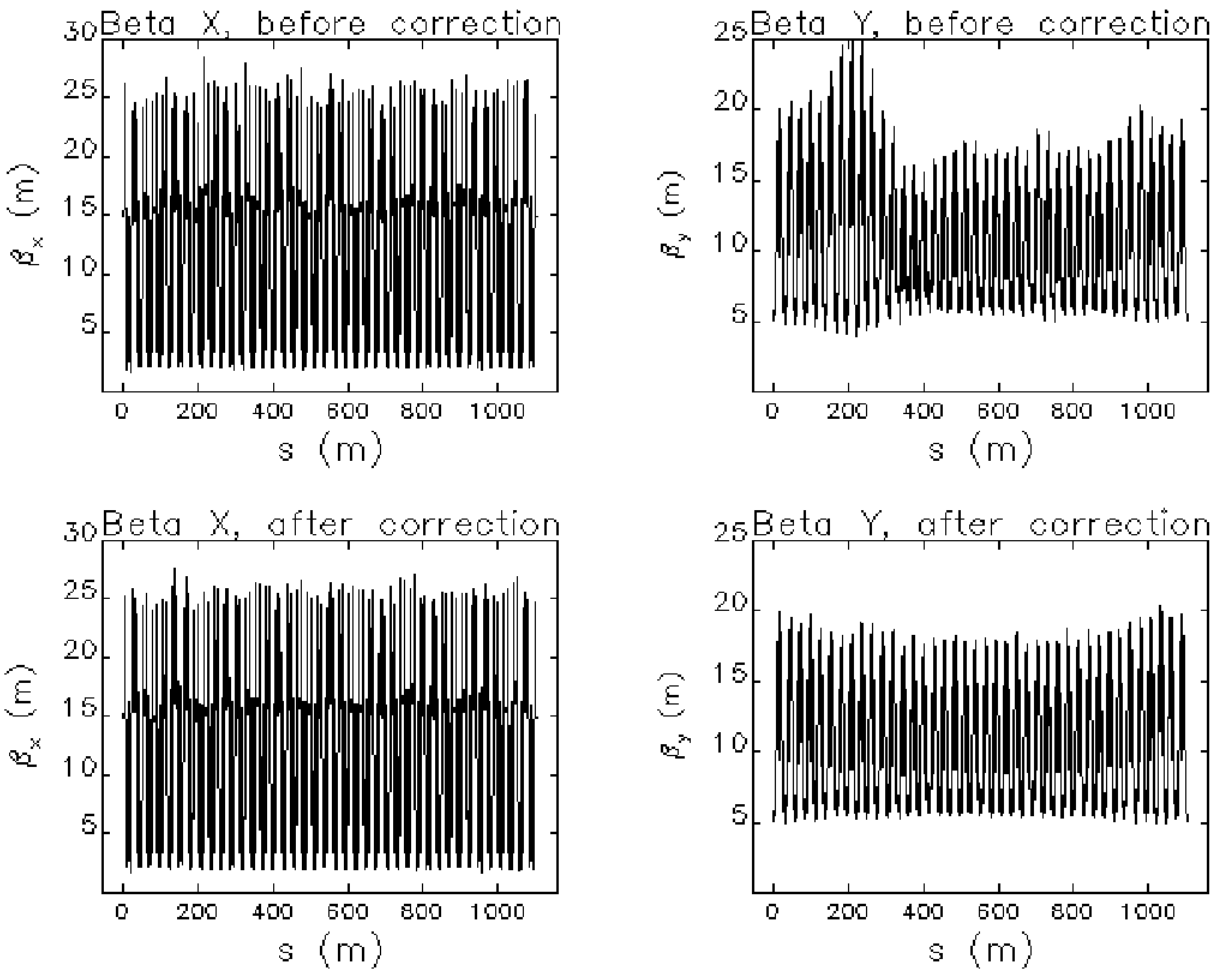


Figure 4. Beta functions of the "high-emittance" lattice before correction (top row) and after correction (bottom row).

*V. Sajaev, L. Emery, "Determination and Correction of the Linear Lattice of the APS Storage Ring", EPAC 2002, http://accelconf.web.cern.ch/AccelConf/e02/PAPERS/TUPRI001.pdf

Applications based on LOCO at the Advanced Photon Source

- Lattice function measurement / correction, including coupling (1% rms)
- Dispersion correction
- BPM gain (calibration) determination (1% rms)
- Local transverse impedance determination (Sajaev, PAC2003)
- Local chromaticity errors (used to find mis-wired sextupole) (Sajaev, PAC2009)
- Sextupole mechanical offset determination (Sajaev, Xiao, IPAC2010
- Development / validation of new lattices in conjunction with comprehensive machine modeling including genetic optimization over many parameters
  - Long straight sections (missing Q1 lattice, asymmetrically places)
  - Short-pulse x-ray crab cavity insertion
  - Increased dynamic aperture / lifetime

Turn-by-turn diagnostics

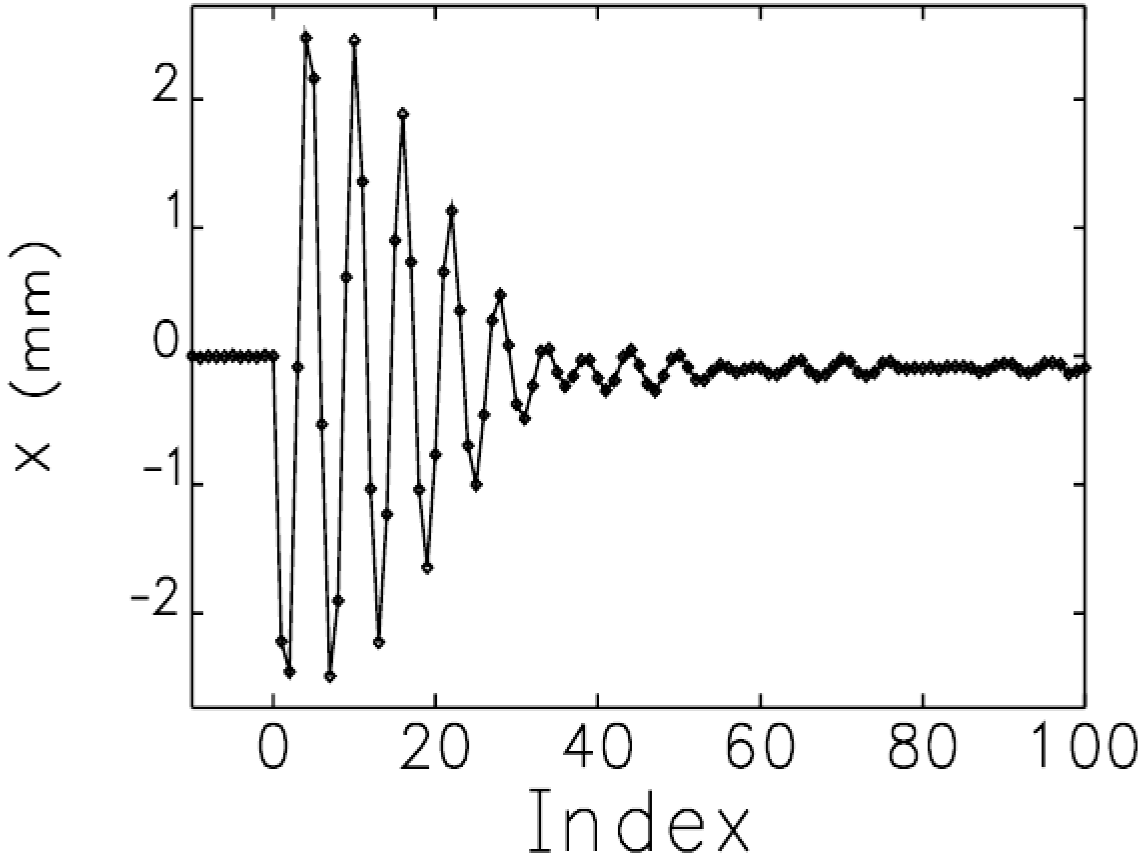
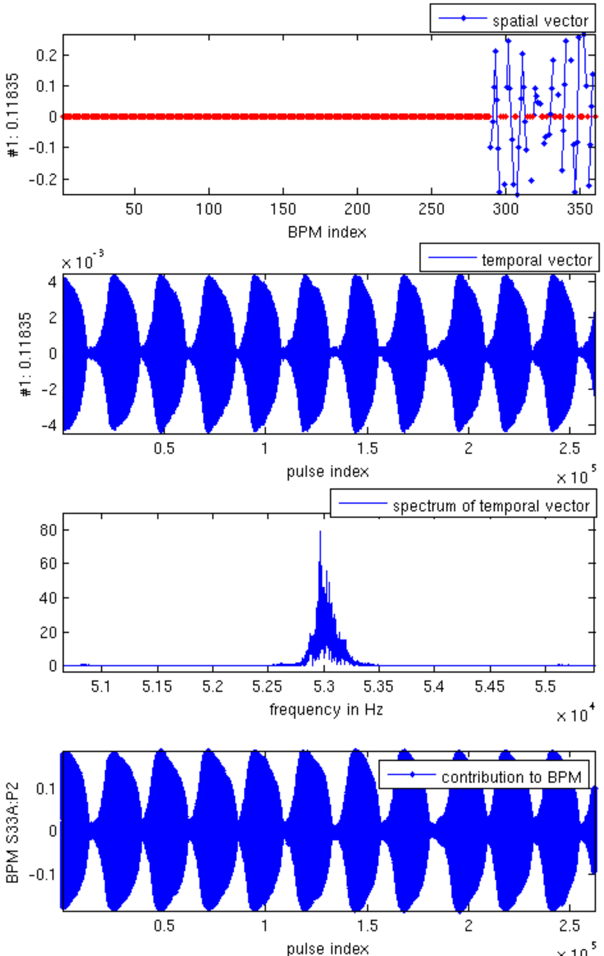


Figure 1: Horizontal betatron motion after injection.

*V. Sajaev, “Use of Turn-by-turn data from FPGA-based bpms during operation of the APS storage ring, IPAC 2010

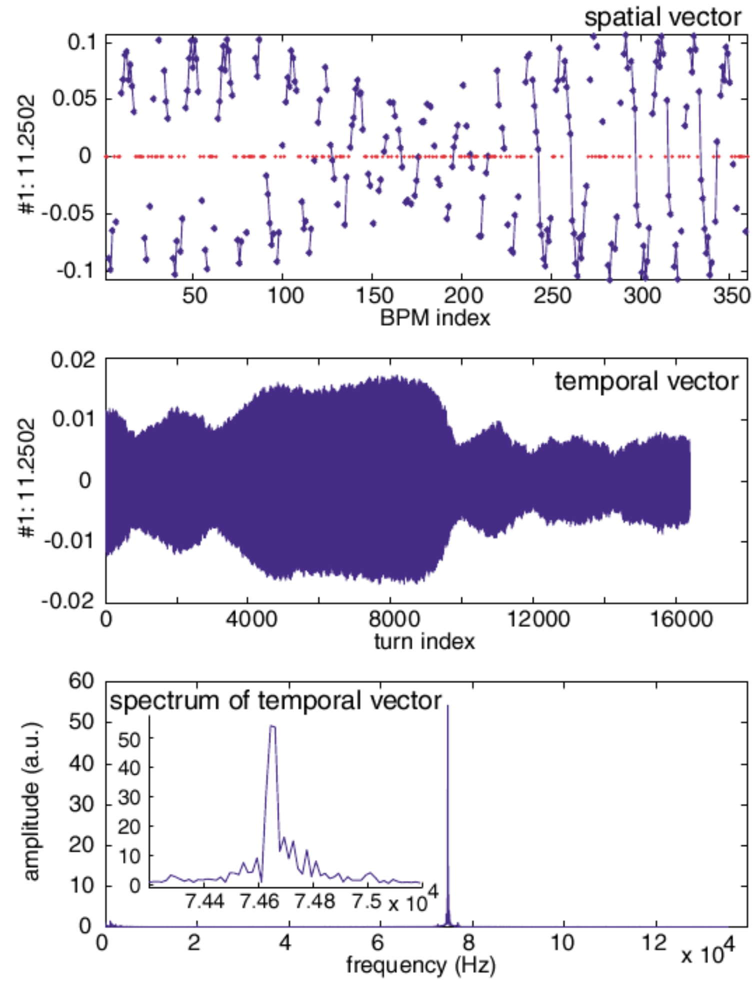
Lattice Determination from Model-Independent Analysis* (Principle-Component Analysis)

Horizontal Sawtooth Instability



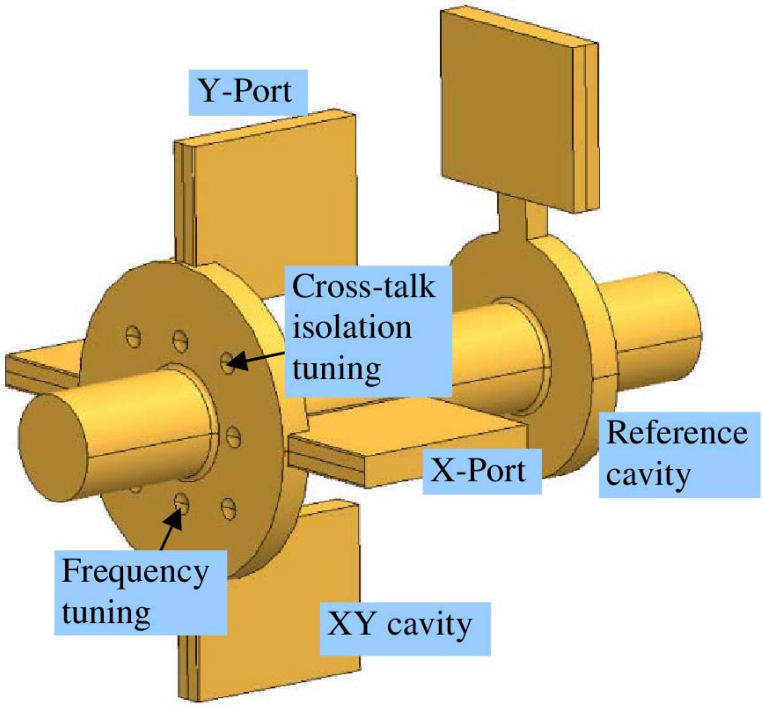
One Second = 2^{18} turns

Vertical Resonant Excitation



*Chun-xi Wang, V. Sajaev, C.Y. Yao, "Phase advance and beta function measurements using model-independent analysis", prst-ab 6, 104001 (2003)

X-Band Cavity BPM Designed for LCLS



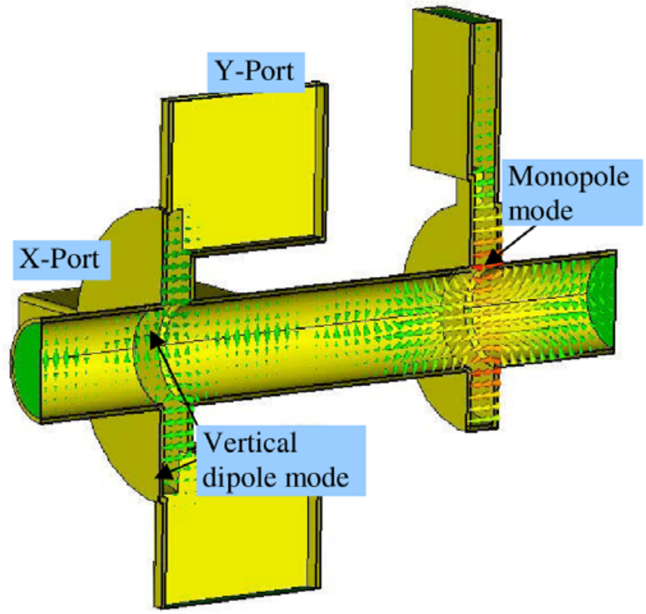
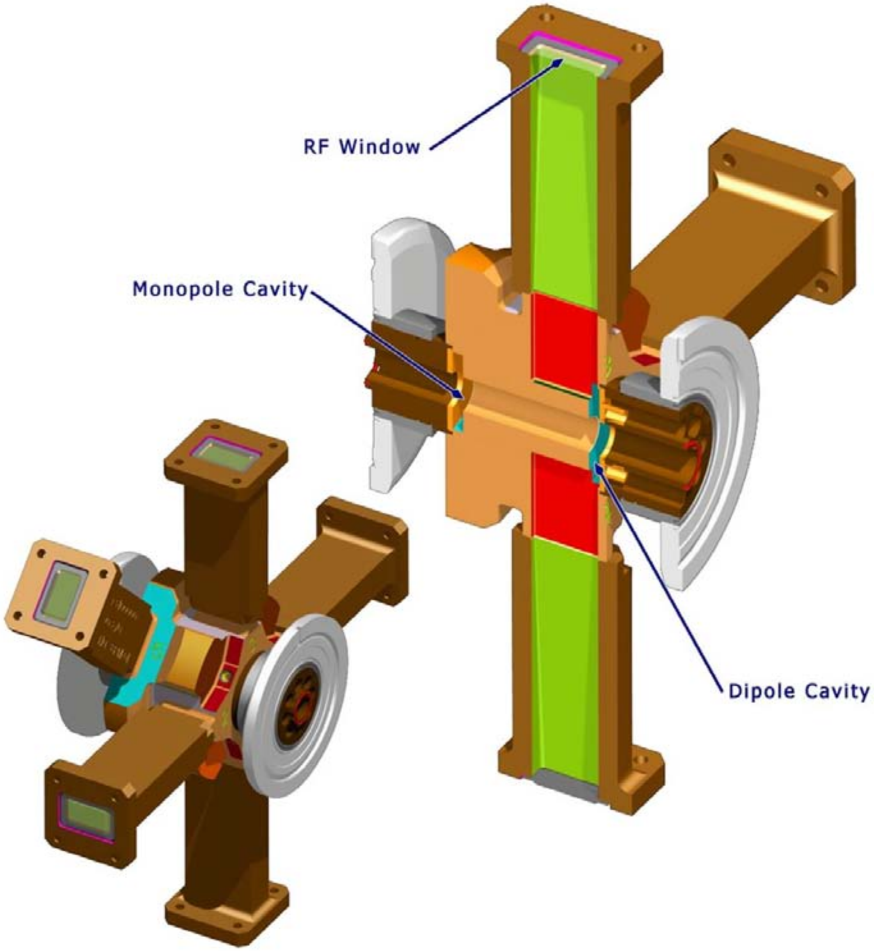
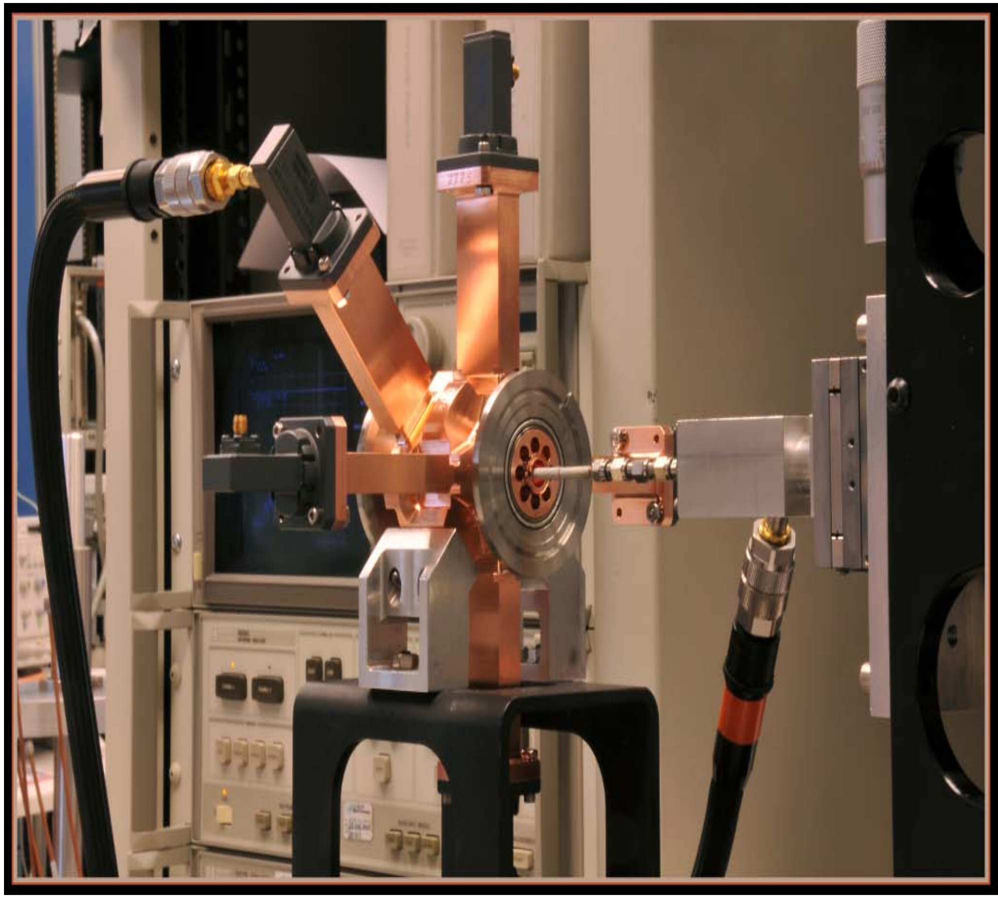


Figure 2: Electric field vectors at 11.384 GHz produced by the wakefield of a 1-nC, 300-fs Gaussian bunch with 1-mm vertical offset.

G. Waldschmidt, R. Lill, L. Morrison,
"Electromagnetic Design of the RF Cavity Beam Position Monitor for the LCLS
PAC 2007

X-Band Cavity BPM Designed for LCLS





Beam-Based Alignment using Cavity BPMs at LCLS

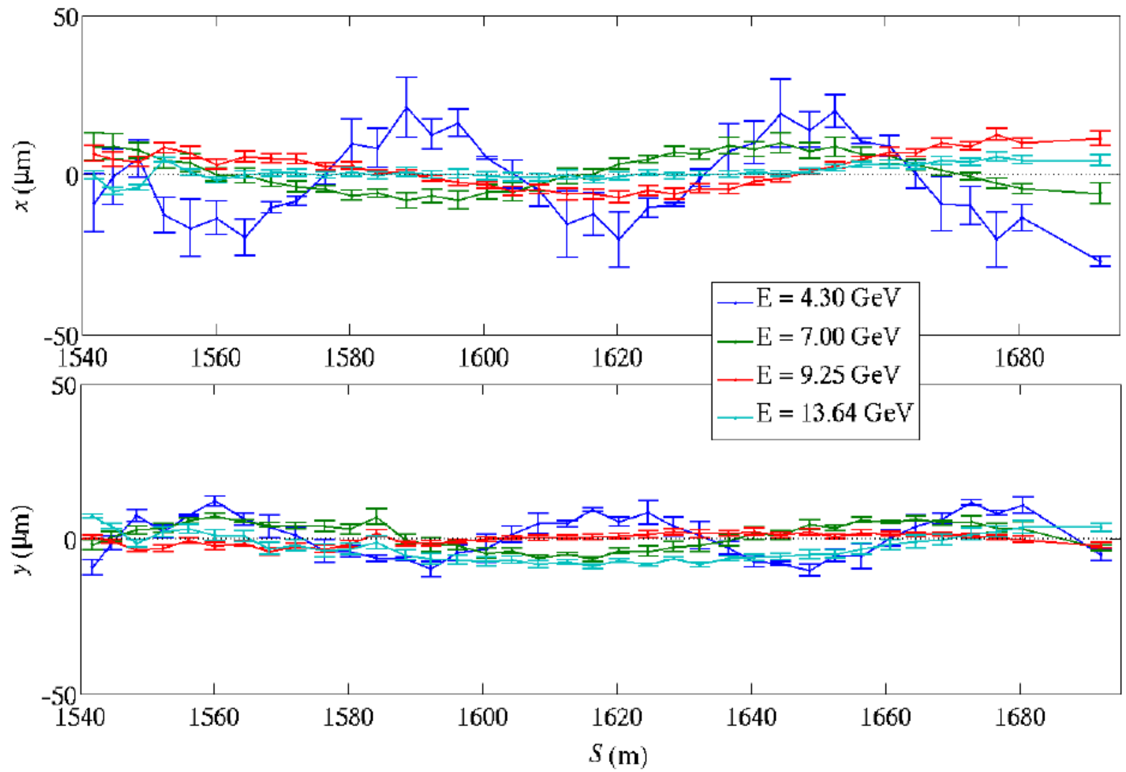
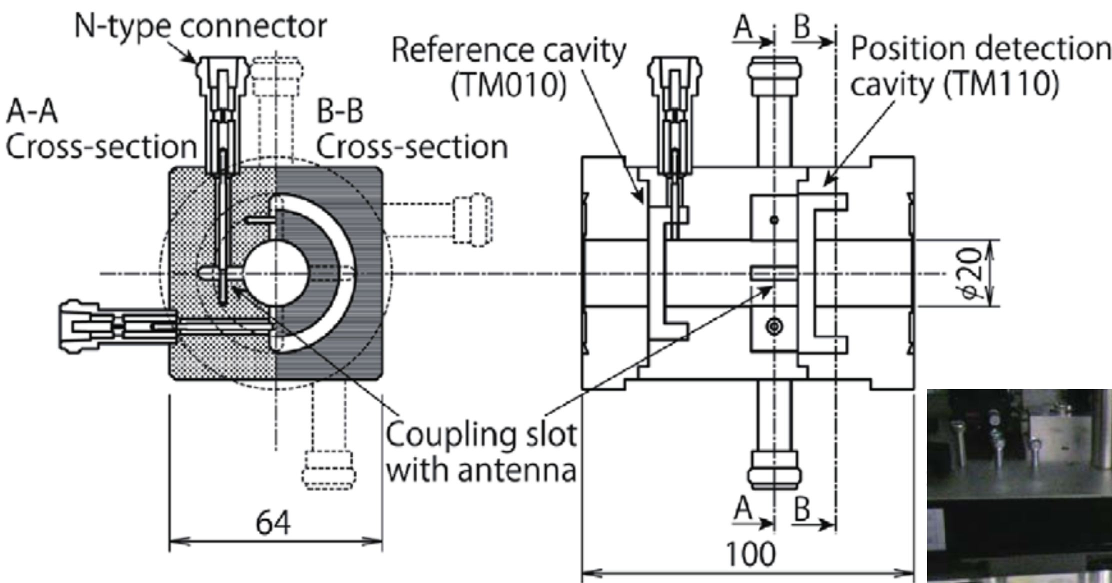
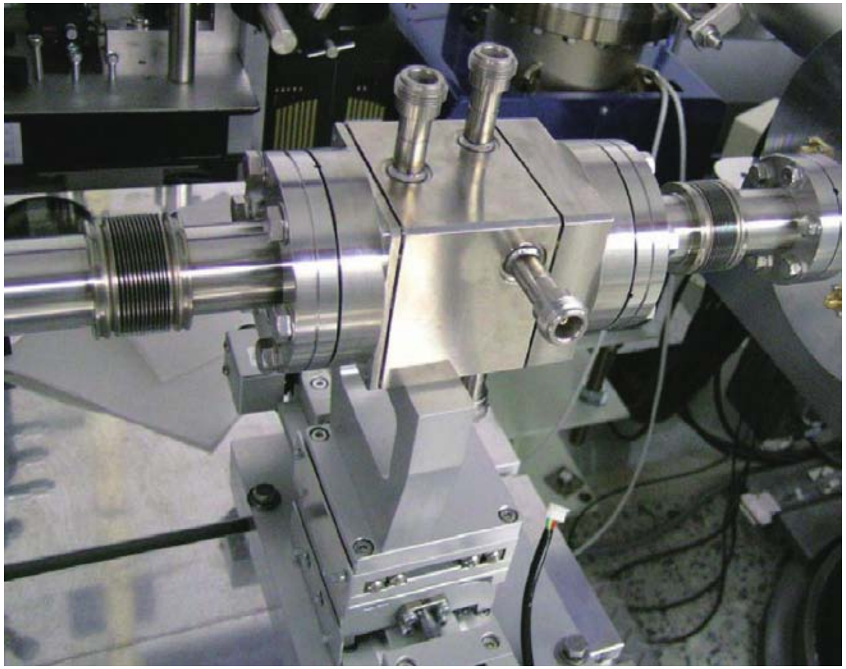


Figure 9: Undulator *x* (top) and *y* (bottom) trajectories at four different electron energies (4.3, 7.0, 9.25, and 13.6 GeV) showing the trajectory is highly dispersion-free and well aligned.

*Paul Emma etal., "First Lasing of the LCLS X-ray FEL at 1.5 Angstroms", PAC 2009, http://accelconf.web.cern.ch/AccelConf/PAC2009/papers/th3pbi01.pdf

Spring-8 XFEL C-Band Cavity BPM (Shintake)





H. Maesaka etal.,
“DEVELOPMENT OF THE RF CAVITY BPM OF XFEL/SPRING-8”
DIPAC 2009

Summary

- Sub-micron one-hour drift is now routine at light sources
  - Allows very accurate determination of lattice functions, BPM gains, etc. using response matrix least-squares fitting.
- Large deployments of synchronous turn-by-turn bpms open up huge possibilities in terms of very accurate phase determination, non-linear dynamics studies (e.g passive amplitude-dependent tune determination) and much more.
- Sub-micron single-shot capability at FEL's allows clean beam-based alignment and stable operation.